Vol. 8 No. 1 SPRING 2022

THE MAGAZINE FOR THE METAL ADDITIVE MANUFACTURING INDUSTRY

METAL AM

in this issue

PANGEA: MAKING THE UNMAKEABLE

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HÖGANÄS AB ON METAL POWDERS

Published by Inovar Communications Ltd

www.metal-am.com

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Subscriptions
Metal Additive Manufacturing is published on a quarterly basis as either a free digital publication or via a paid print subscription. The annual print subscription charge for four issues is £150.00 including shipping. Rates in € and US$ are available on application.

Printed by
Cambrian Printers, Aberystwyth, UK

ISSN 2057-3014 (print edition)
ISSN 2055-7183 (digital edition)
Vol. 8 No. 1 Spring 2022

This magazine is also available for free download from www.metal-am.com

METAL ADDITIVE MANUFACTURING

Changing industry dynamics: AM versus AM

Until very recently, when one spoke about making a commercial product by metal Additive Manufacturing/3D printing, it was almost a given that the process being used would be Laser Beam Powder Bed Fusion (PBF-LB). This is, without doubt, the process that has gained the most traction over the last ten years, enjoying the fastest rate of technical development thanks, in large part, to the performance and efficiency gains it offered to the aerospace industry.

Now, things are changing. No longer is the storyline simply 'AM versus subtractive manufacturing' — there is a noticeable increase in competition between metal AM processes: 'AM versus AM.'

Most visible is the rise of sinter-based AM processes such as Binder Jetting (BJT), Material Extrusion (MEX) variants such as Fused Filament Fabrication (FFF), Vat Photopolymerisation (VPP) and unique variants such as the hybrid binder-based technology developed by Headmade Materials.

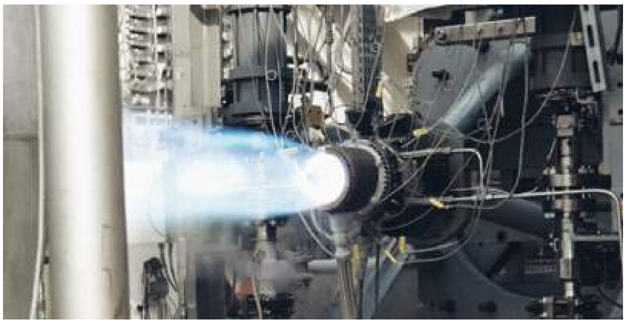
One example of intra-AM competition is seen in the cycle industry. The frame components that Headmade now produces for Sturdy Cycles with its sinter-based AM technology compete directly with the equivalent parts being produced in-house using PBF-LB by Atherton Bikes, as featured in this issue.

We will no doubt see many more examples of metal AM processes competing with each other in the near future. Assuming that all processes can deliver on mechanical performance and process stability, it is inevitable that process economics will be the deciding factor in the coming AM versus AM race to industrial adoption. It will be fascinating to see how factors such as machine cost, powder specifications – and, hence, cost – and build speed play out in real-world high-volume applications.

Nick Williams
Managing Director

Cover image
The DemoP1 is the first AM aerospike engine in the world to be powered by liquid methane and liquid oxygen (Courtesy Pangea Aerospace)

Contents



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3D SYSTEMS

151 **What does a decades old metal powder titan bring to Additive Manufacturing? In conversation with Höganäs AB**

The metal Additive Manufacturing landscape is filled with ambitious, well-funded startups, all promising a wealth of materials innovation and ambitious value propositions.

In contrast to these newcomers, Höganäs AB has been a powerful force in the metal powder market for near eighty years, producing half a million tonnes of metal powder annually. Is there a role for such a titan of Powder Metallurgy in the brave new world of AM?

Emily-Jo Hopson-VandenBos spoke to Kennet Almkvist, president, Höganäs Customization Technologies, about what the company brings to the table. >>>

167 **Innovation to commercialisation: Atherton Bikes and the journey of an SME bringing AM production in house**

Bringing Additive Manufacturing in house is a big step for any company, but when you are at the small end of the 'SME' spectrum, it can be an especially bold move.

Robin Weston recently visited Atherton Bikes, based in rural west Wales, to see how this specialist bike producer is enjoying ramping up in-house production of its titanium and carbon fibre performance mountain bikes on a new, four-laser Powder Bed Fusion (PBF-LB) machine from Renishaw. >>>

175 **A game of hide and seek with Renishaw and Altair: AI-powered quality assurance on the fly**

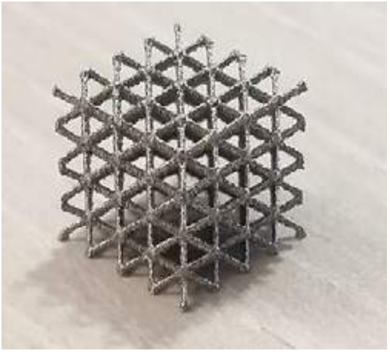
Is it possible to actively monitor the huge volumes of data from a Laser Beam Powder Bed Fusion (PBF-LB) machine to identify, through machine learning (ML), build errors as they happen? To answer this question, Renishaw and Altair played a unique game of hide and seek.

In this innovative experiment, an error was deliberately hidden in a build for an artificial intelligence (AI)-based solution to find. The hope? True 'on the fly' quality assurance for Additive Manufacturing processes for accelerated product development, and dramatically reduced post-production quality checks. >>>

185 **Opening the discussion: How the humble bottle opener demonstrates the importance of requirements in AM**

Designs not driven by requirements increase the risk of an incomplete solution. This relatively simple statement gets to the heart of how designers need to be approaching AM, particularly when balancing the 'design freedoms' offered by the technology with the reality of viable and profitable production.

Through an exploration of the ubiquitous AM bottle opener, John Barnes, Jennifer Coyne and Chelsea Cummings, The Barnes Global Advisors, and Jon Meyer, APWorks, explore how, by focusing on requirements, a data-driven approach ensures fully functional designs that deliver on multiple requirements for the lowest cost. >>>



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Industry news

Airbus, Safran and Tikehau Ace Capital to acquire Aubert & Duval

Airbus, Safran and Tikehau Ace Capital have signed a Memorandum of Understanding with the mining and metallurgical company Eramet Group, headquartered in Paris, France, for the acquisition of its subsidiary Aubert & Duval. The three partners intend to acquire 100% of Aubert & Duval through a new joint holding company that would be established specifically for this transaction, in which they would have equal ownership rights.

Aubert & Duval is a leading supplier of metal powders for Additive Manufacturing and other powder-based part production technologies, serving demanding markets such as aerospace, energy, medical, defence and automotive. The company has annual revenues of approximately €500 million and a workforce of around 3,600, mostly based in France.

The acquisition is expected to enable Airbus and Safran to secure the strategic supply chain (for themselves as well as customers) and new material development for current and future civil and military aircraft and engine programmes. It is also consistent with the initiatives taken in the last few years to support the French aerospace industry's supply chain, and in particular the creation, with the help of the French State, of the Ace Aéro Partenaires fund managed by Tikehau Ace Capital.

"Aubert & Duval is a historical supplier of Safran with unique technical expertise in Europe," stated Olivier Andriès, Safran's CEO. "The planned acquisition will ensure national sovereignty for our most strategic programmes for disruptive civil and military aircraft engines. Given its industrial expertise in metallurgy, Safran will lead the operational management of the company. The transformation programme will reinforce customer confidence and create a national champion with a strong French industrial base capable of serving global markets."

Guillaume Faury, Airbus CEO, commented, "Aubert & Duval, with its critical knowledge and expertise dating back more than a century, is a strategic supplier to Airbus and the entire aerospace and defence industry. Our sector, which has started to emerge from the COVID crisis, needs a solid partner to ramp up production while preparing next-generation technologies in aerospace. With this acquisition and an ambitious transformation plan, we aim to restore the operational excellence and market confidence in Aubert & Duval to create, in the mid- to long-term, a leading European player able to face global competition as well as to reduce geopolitical risk of supply."

Marwan Lahoud, Executive Chairman of Tikehau Ace Capital, added, "This joint acquisition sends a strong and very encouraging message about the acceleration of the restructuring, the transformation and the consolidation of the supply chain in the aerospace industry. Together with Airbus and Safran, by bringing the capital and top industrial expertise needed to leverage the strategic excellence of Aubert & Duval, we are proud to contribute to support the recovery of the sector at the most critical time, when aeronautical companies have to invest again to accompany the revival of activity and project themselves into the future."

The proposed transaction is subject to consultation with relevant employee representative bodies and all necessary regulatory approvals. It is expected to close in the fourth quarter of 2022.

www.safrangroup.com
www.airbus.com
www.tikehau-ace.capital
www.aubertduval.com
www.eramet.com

Airbus, Safran and Tikehau Ace Capital are to jointly acquire Aubert & Duval, a leading supplier of metal powders for Additive Manufacturing (Courtesy Safran Group/M Labelle)

China's Wenext orders thirty metal AM machines from HBD

China's largest Additive Manufacturing service bureau, Shenzhen Wenext Technology Co, Ltd (Wenext), headquartered in Shenzhen, China, has signed an agreement with Guangdong Hanbang 3D Tech Co, Ltd (HBD), Zhongshan, to deepen cooperation and establish a long-term, comprehensive strategic partnership. As part of the agreement, Wenext has ordered thirty new HBD-350T metal Additive Manufacturing machines from HBD.

Wenext was launched in 2015 and has grown into a multi-process service bureau with around a thousand polymer AM machines as well as CNC machining centres, sheet metal equipment, injection moulding systems, vacuum casting and inspection equipment. The company turned to HBD in order to meet customer demand for metal AM services.

In this strategic cooperation, both parties are committed to advancing the digitisation of manufacturing and the large-scale production of small batches. Both companies believe that the cooperation will expand opportunities and serve as a win-win for both parties and manufacturing as a whole.

Mao Yi, General Manager of HBD, said that HBD aims to help Wenext upgrade process technology and equipment. One such step already taken is that HBD has developed software for overseeing operation, data processing and intelligent management, which can connect with Wenext's internal information software platform. This vertical integration is anticipated to improve manufacturing efficiency, further expanding Wenext's product service capabilities.

www.wenext.com
en.hb3dp.com

Wenext have ordered thirty HBD-350T metal AM machines from HBD (Courtesy HBD)

Seurat Technologies boosts funding with a further $21M round

Seurat Technologies, Wilmington, Massachusetts, USA, has closed a $21 million Series B extension round with funding from new investors Xerox Ventures and SIP Global Partners. The latest round also has participation from previous investors Capricorn's Technology Impact Fund, True Ventures, Porsche Automobil Holding SE, and Maniv Mobility. This brings the total funding for Seurat to $79 million.

The funding will support Seurat's aim to decarbonise manufacturing and address supply chain issues with the company's Area Printing technology, a metal powder-based AM process, that is reportedly powered by 100% renewable energy. This is expected to help companies migrate manufacturing from castings and other traditional fabrication methods to achieve high-volume production and reduce harmful environmental pollutants. When operating at full production capacity, Seurat expects to displace 0.15 gigatons/year of carbon emissions by 2025.

"Seurat's mission is to make manufacturing better in every way by embracing the agility and design freedom of 3D printing, but not at the same expense," commented James DeMuth, co-founder and CEO of Seurat. "Area Printing decouples resolution and speed, which is the secret sauce to making 3D printing a high-volume process. We are working with the world's largest manufacturers in migrating their designs to Area Printing to help them gain lead-time, cost, and quality advantages, while making a positive environmental impact."

Seurat states that it has already secured seven letters of intent to join its commercialisation programme from leading automotive, aerospace, energy, consumer electronics, and industrial companies, and expects to launch its first commercial programmes this year. The additional funding will be used towards building Seurat's production-grade system which is targeted to produce parts at $300/kg — comparable to parts produced by machining. By 2025, Seurat anticipates lowering manufacturing cost to $150/kg, which is comparable to castings. As Seurat grows, it intends for its technology to make the $1 trillion metal manufacturing market fully accessible to AM.

Tim Chiang, Investment Director at Xerox Ventures, said, "Xerox Ventures is investing in high growth startups that usher forth truly transformative business solutions across all industries. We believe that the future of how we make products will solve for today's supply chain and sustainability challenges, and Seurat will help make that future a reality for mass production with their breakthrough advanced manufacturing technology."

www.seuratech.com

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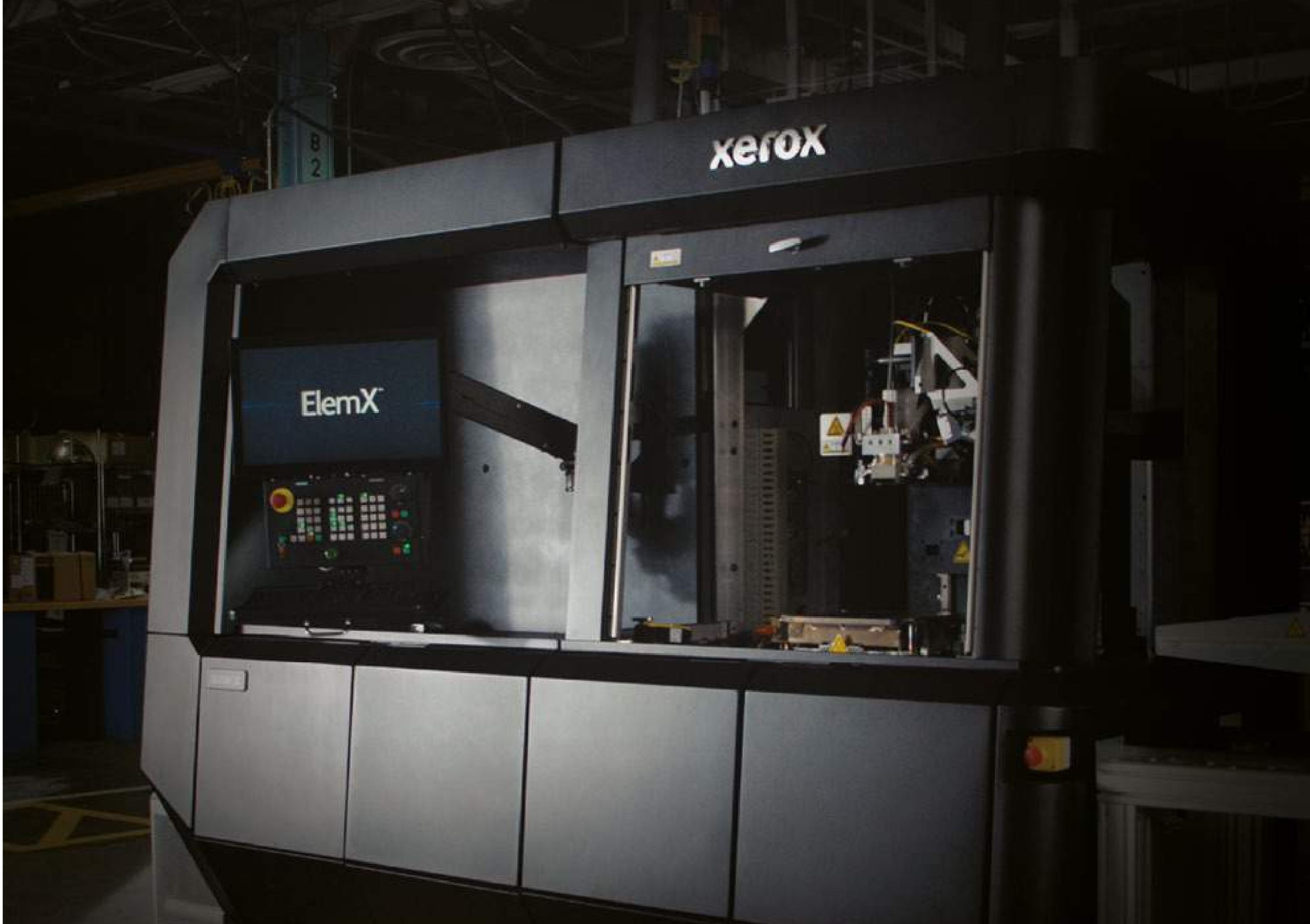

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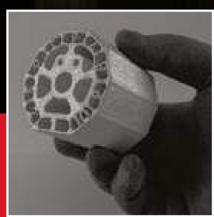

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Desktop Metal adds X-Series Binder Jetting machines

Desktop Metal, Boston, Massachusetts, USA, has added the X-Series line of Binder Jetting (BJT) machines for metal and ceramic powders. The model line is derived from the acquisition of the ExOne Company and is planned to be offered with Desktop Metal's build preparation and sintering simulation software applications.

The company states the X-Series line offers a differentiated approach to Binder Jetting, enabled by patented Triple ACT compaction technology for dispensing, spreading and compacting powders during the BJT process. This open material platform architecture is said to be capable of binding together a wide range of powders with a D50 of 3–100 µm.

The line can also reportedly deliver tight dimensional tolerances and densities of 97–99% or greater — in line with or surpassing Metal Injection Moulding (MIM) or gravity castings - and surface roughness values as low as 4 µm (Ra) can be achieved directly out of the furnace. Desktop Metal now offers three X-Series models, which include the InnoventX™, X25Pro™ and the X160Pro™.

"Desktop Metal's X-Series printers give customers more choices than ever when it comes to binder jet Additive Manufacturing" stated Ric Fulop, Desktop Metal Co-founder and CEO. "Our team is moving aggressively to drive Additive Manufacturing into mass production through a focused strategy of production-capable printers, high-performance materials, and key applications. Binder Jetting is the key technology that enables all the benefits Additive Manufacturing has to offer at scale, from reduced waste to more efficient, lower-risk supply chains."

www.desktopmetal.com

Desktop Metal has incorporated the X-Series line of Binder Jetting machines into its range (Courtesy Desktop Metal)

Mitsubishi Electric launches AZ600 wire-based metal AM machines

Mitsubishi Electric Corporation, Tokyo, Japan, has launched the AZ600, a wire-based Directed Energy Deposition (DED) metal Additive Manufacturing machine. According to Mitsubishi Electric, the AZ600 is the first machine of its type that combines simultaneous five-axis spatial control and digital Additive Manufacturing technology, making it ideally suited to maintenance repairs in the automotive, marine and aviation markets, as well as contract Additive Manufacturing services.

Mitsubishi's new AZ600 DED AM machine (Courtesy Mitsubishi Electric Corporation)

Wire-based DED typically uses an arc discharge as its heat source, explains Mitsubushi Electric, which can result in issues with accuracy due to high thermal strain and the impact of heat on material layers. Mitsubishi Electric's new wire-feedstock method solves this by using a laser beam for highly precise control of the heat source, according to the build state, thereby combining moulding accuracy with the advantages of wire feedstock Additive Manufacturing.

The AZ600 uses computerised numerical control (CNC), for the cooperative control of processing conditions such as wire feeding, laser power and axis feed. Due to its high precision, along with reduced energy consumption and waste, the new machine is said to help limit the environmental impact of manufacturing.

The AZ600 is available in two model versions, the AZ600-F20 with a 2 kW laser and the AZ600-F40 having a 4 kW laser. The machine allows a maximum workpiece build diameter of 500 mm and build height of 500 mm.

www.mitsubishielectric.com

EOS launches network to connect companies seeking AM support

EOS GmbH, headquartered in Krailling, Germany, has launched a new end-to-end production network to connect companies seeking high quality serial Additive Manufacturing support with selected certified EOS partners.

With this launch, EOS states that it expands its existing contract manufacturing network with the much-needed end-to-end production component. To become a partner in this network, companies undergo a certification process where the end-to-end capabilities are the key criteria. From part design, to design optimisation for AM, manufacturing capabilities, pre- and post-processing including surface treatment, to quality assurance and assembly to create high-end final parts in series.

From start-up businesses to SME and OEM organisations, bringing products to life at scale can be a demanding experience, particularly if working in a certified industry or wanting high volume production that does not compromise on the quality of the final product, or global distribution.

Once the right AM solution is identified, one of the biggest hurdles can be finding the right manufacturing method and deciding how to organise part production. EOS assists companies by identifying the best application & technology framework and consults companies on in-house vs. external production. If a third-party production partner is the best choice, then there are other important considerations. Businesses not only need partners that are solidly positioned and can produce high-quality additively manufactured parts at scale, but which also share the end-customer commitment to creating the right product and have the experience needed to bring products to the market.

EOS explains that its end-to-end production network partners will be able to help companies mitigate these risks and move rapidly to final serial part production on a large scale. Members will be able to bring their expertise from a range of manufacturing technologies to help them ramp-up production at speed, ensuring quality standards throughout and support every aspect of an end-to-end production.

The network will initially be set up in the EMEA region with Prototal Industries, Jönköping, Sweden, being the first AM company to join the network.

Markus Glasser, Senior VP EMEA at EOS, commented, "With more than thirty years of experience in offering comprehensive Additive Manufacturing solutions, EOS understands market requirements for AM series production. With this network we want to create added value for both parties involved – those offering manufacturing services and those in search for it. This will take much of the complexity and risk out of choosing a manufacturing partner for serial production businesses, with the most innovative product designs. They will be able to bring products to market faster, using the latest state-of-the-art 3D printing technology, and draw on the vertical industry expertise and know-how within the network."

www.eos.info/en

Headmade Materials raises over €8 million in funding

Parts additively manufactured using Headmade Materials' Cold Metal Fusion process (Courtesy Headmade Materials GmbH)

Headmade Materials GmbH, Wuerzburg, Germany, has been selected for the EU Commission's EIC Accelerator programme. As such, the company will receive €5.85 million in support from the programme in an effort to bring its technologies to market faster, placing it among the programme's top ten German companies.

"The funds from the EIC Accelerator programme will give us the additional resources we need to increase our speed even more and offer our technology to a broader international customer base," stated Marius Geldner, CFO of Headmade. "Speed is one of the keys to success, especially in the international competitive environment."

Headmade also closed a €2.5 million Series A financing round with Additive Manufacturing specialist AM Ventures as the lead investor. The btov Industrial Technologies Fund also participated in the funding round as an existing shareholder.

"With decades of experience in industrial 3D printing, AM Ventures is the perfect fit for us," stated Christian Staudigel, CEO and co-founder of Headmade Materials. "In addition, the collaboration with our existing investor btov Industrial Technologies Fund has already worked excellent within the Additive Manufacturing market. With the support gained, we will accelerate the transformation of metal 3D printing into volume production and, together with our customers, bring numerous applications to market."

The sinter-based Additive Manufacturing process used by Headmade, Cold Metal Fusion, enables the series production of complex metal parts in large quantities of over 100,000 parts. This distinguishes the process from common metal AM processes, which may be more limited in terms of both speed and manufacturing costs for larger series.

The company states that it will use the funds for the extensive expansion of production capacities, the product portfolio and international sales. It will also use the additional funds to provide international users access to the company's technology and to greatly expand production capacities for its own feedstock material. On the product side, further materials and alloys will be released and optimised hardware will be made available in cooperation with partners.

Arno Held, Managing Director of AM Ventures, commented, "We have been observing Headmade Materials for quite some time and are impressed by the company's development in the last few years. The great scope of applications the technology enables and the successful projects that the team of Christian Fischer and Christian Staudigel have carried out speak for themselves. We are very excited to now have become part of the Headmade journey and to take the next steps together."

www.headmade-materials.de

Kingsbury establishes metal Additive Manufacturing parts venture Additure

Kingsbury has launched Additure, a new metal AM parts business (Courtesy Kingsbury)

Engineering equipment supplier Kingsbury, headquartered in Gosport, Hampshire, has launched Additure, a new metal Additive Manufacturing parts business. The company decided to establish the business after being a long-time investor and distributor of AM machinery.

"Everybody is very keen to understand what this technology can do, but there's not been enough interest to warrant a substantial capital investment in machines," commented Richard Kingsbury, Managing Director.

The company states that the goal of Additure is to deliver a no-nonsense approach to Additive Manufacturing, making it easier to understand. Many who are already enthusiastic about the benefits of metal AM have yet to decide to invest, and this largely stems from a lack of helpful information and available education. Additure is said to commit to showing and simplifying the processes, technology and mechanics so more people see that AM is a tool.

Ian Brooks, Technical Director at Additure, added, "Additure intends to grow the market by breaking Additive Manufacturing down into the simple questions: why, how, and when. Customers and partners can be assured that we will be open and transparent to help develop their knowledge base and better establish this tool."

Further information about Additure is available through Kingsbury's website.

www.kingsburyuk.com

Equispheres receives $3.5M investment for metal AM powder production

Equispheres, Ottawa, Ontario, Canada, reports that it will receive a $3.5 million investment from the Federal Economic Development Agency for Southern Ontario (FEDDEV), Ontario Business Scale-up and Productivity Program to accelerate production of its metal powder materials for Additive Manufacturing. The investment was announced as part of the Government of Canada's commitment to innovation and climate change.

"Equispheres metal powders have unique properties that enable faster production of stronger, lighter and more reliable 3D printed parts," stated Kevin Nicholds, CEO. "This contribution will allow us to scale up our production process and take advantage of an exponentially growing opportunity in the 3D printing space."

The company's metal powders are used for AM parts in the automotive and aerospace sectors, where the need for lightweight, high-precision parts manufactured with high repeatability and mass production speeds is essential.

"Equispheres aims to enable industrial 3D printing to compete with traditional manufacturing," Nicholds added. "Our metal powder technology dramatically reduces the cost of 3D part production such that it is economically viable in volume manufacturing applications such as automotive."

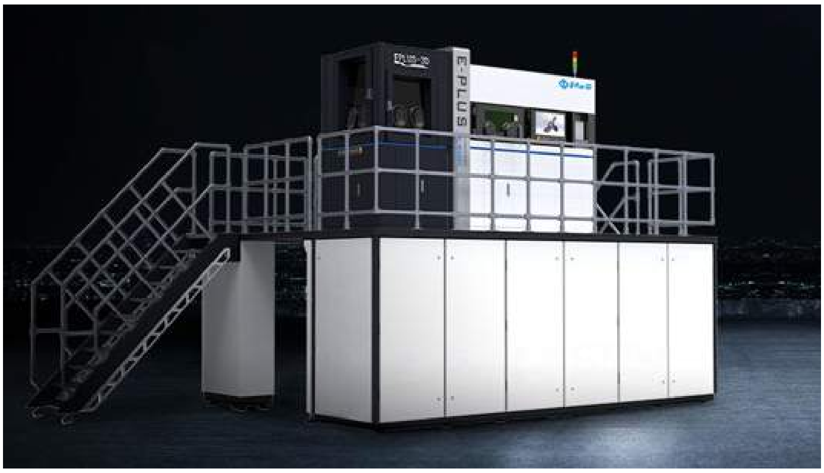
Recent testing by equipment manufacturer Aconity3D demonstrated Equispheres' high-performance feedstock can additively manufacture three times faster than traditional powders and achieve part cost reductions of 50%. Equispheres states that its materials can help Canadian and global manufacturers adopt AM methods that are efficient, sustainable and cost-competitive. In addition, the company has expanded the automotive expertise of its management team by adding Thomas Bloor to lead global business development. Rob Wildeboer, executive chairman of automotive supplier Martinrea International, has joined the board of directors. Calvin Osborne also joined Equispheres in December as Chief Operating Officer.

"We are grateful for the Government of Canada's strong leadership on climate action and programs that support this kind of cleantech innovation. This significant investment by FEDDEV will support the next steps in our growth: working with partners in the automotive, aerospace and defence sectors to qualify our materials for industrial applications," concluded Nicholds.

www.equispheres.com

Eplus3D launches its tallest metal Additive Manufacturing machine

Eplus3D, headquartered in Hangzhou, China, has launched the EP-M450H, a Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machine with a build chamber measuring 455 x 455 x 1100 mm, for use in aerospace, aviation, automotive and defence applications. The EP-M450H can operate with a variety of metal powders such as titanium, aluminium, nickel, and copper alloys; stainless steel and maraging steel; and cobalt chrome. The system features a bi-directional powder recoating method which can lead to a reduced re-coating time and repeatable positional accuracy along Z-axis of building direction ≤± 5 µm.



The EP-M450H features a build chamber of 455 x 455 x 1100 mm (Courtesy Eplus3D)

There is a dual laser system with two 500 W fibre lasers. The overlapping deviation between the two is ≤±0.1 mm, meaning the overall mechanical properties are comparable to parts built with a single laser machine. The build rate for the machine is up to 55 cm^3/h, with density up to 99.9% and <5% deviation in mechanical properties.

The sustained monitoring of powder left in the feeder, and the ability to add powder without stopping the machine, enables uninterrupted part building during which a real-time display is available for various sensors.

Reduced gas consumption during build time, ≤6 litres/min, helps to lower operation cost, while the blow back enabled filtration system is intended to remain active for over 1,000 hours.

The integrated process software offers the ability to divide the build model into different sections, for which process parameters can be individually applied. This can be integrated with Siemens NX software to realise design planning as part of the same system.

www.eplus3d.com

JEOL tabletop scanning electron microscopes for quality control in Additive Manufacturing

As the Additive Manufacturing industry grows, so does the demand for high-throughput scanning electron microscope (SEM) imaging and analysis techniques such as energy-dispersive X-ray spectroscopy (EDS). JEOL USA Inc, headquartered in Peabody, Massachusetts, USA, a wholly-owned subsidiary of JEOL Ltd. Japan, is a leading provider of these systems and has introduced a number of options suitable for the AM sector.

SEMs are powerful tools that reveal surface details at nanoscale resolution, explains JEOL. In quality control, these microscopes are useful for profiling structural, morphological and topographical characteristics. EDS goes a step further, providing compositional information from the X-rays produced when electron beams generated by tabletop electron microscopes interact with a specimen.

The JCM-7000 NeoScope™ is a benchtop SEM equipped with real-time 3D imaging, advanced auto functions and the option to add a fully embedded EDS with real-time analysis. The combination of high-resolution imaging and chemical analysis capabilities reputedly enables more detailed failure analysis than is achievable with optical microscopes alone. JEOL believes that the machine is suitable for AM producers, in that it can characterise size distribution, particle homogeneity and foreign contaminants to determine the purity of materials at nanometre scales.

The benchtop JCM-7000 NeoScope SEM optionally features a fully embedded EDS (Courtesy JEOL)

With the growing complexity of industrial applications, manufacturers need QC processes that are fast, reliable and scalable. Manufacturers may opt for tabletop electron microscopes as they are easily calibrated to recognised standards, thus making it straightforward to repeat tests within a set of parameters.

Materials defects often occur at the nanometre scale, meaning a high degree of resolution is essential. SEMS use electrons instead of light to 'see' into materials. Since electron wavelengths are up to 100,000 times smaller than the wavelengths of visible light, electron microscopes resolve details hundreds of thousands of times smaller than optical microscopes.

Tabletop electron microscopes are also able to provide comprehensive chemical composition information when combined with EDS instruments. In quality control, for example, such a combination can help determine the thickness of coatings, the sizes of particles and grain boundaries.

www.jeolusa.com
www.jeol.co.jp

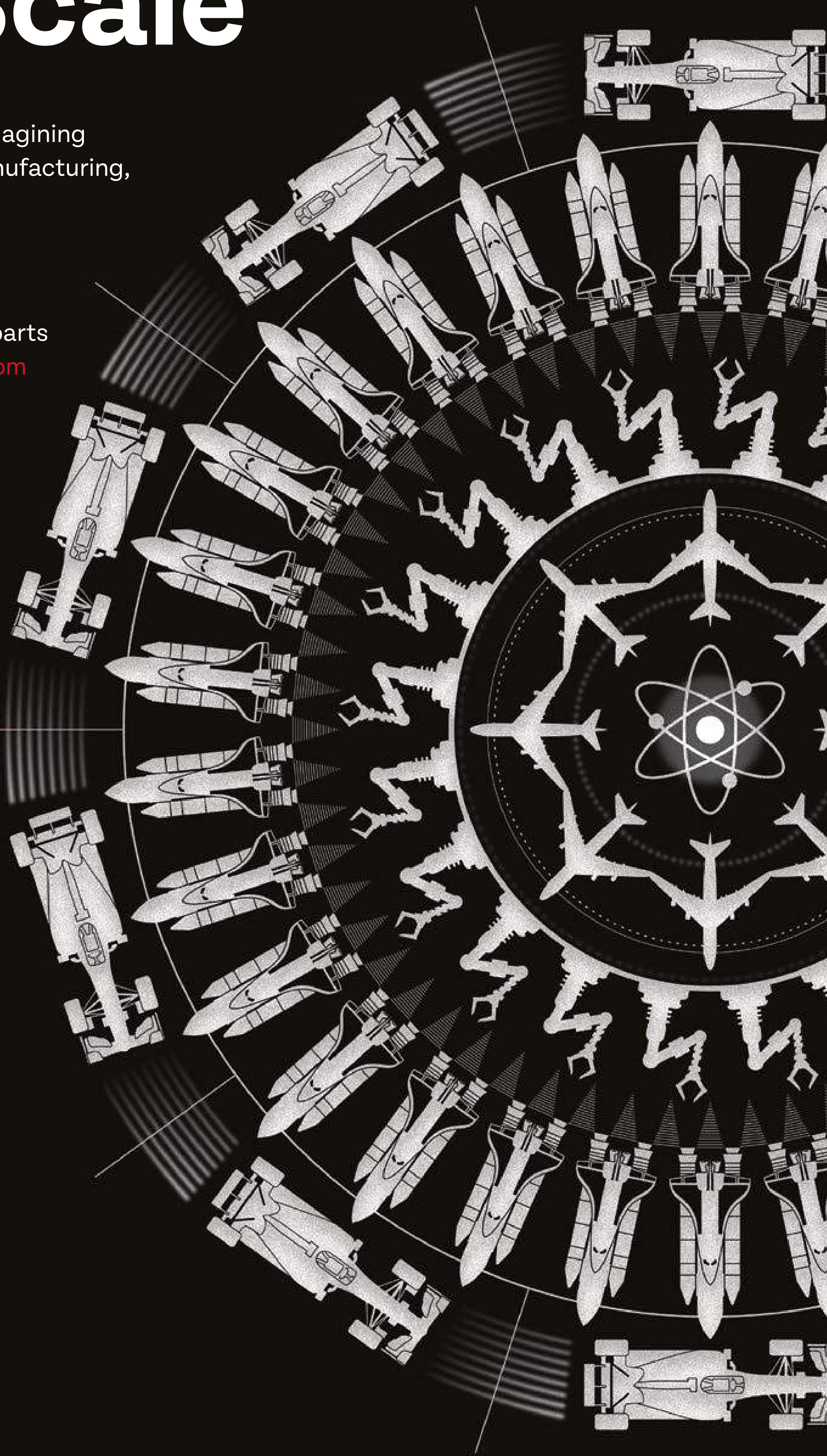
Carpenter Technology reports increase in sales as demand continues to improve

Carpenter Technology Corporation, Philadelphia, Pennsylvania, USA, has announced financial results for its fiscal second quarter ended December 31, 2021. Net sales for the period were $396 million, up from $348.8 million in the second quarter of the fiscal year 2021, an increase of 14% on a 9% increase in shipment volume. Net sales excluding surcharge were $314.9 million, an increase of $15.5 million (or 5%) from the same period a year ago. The results are said to reflect higher shipments to the medical, transportation, industrial and consumer and distribution end-use markets, partially offset by lower shipments to the aerospace & defence and energy end-use markets. For the quarter, however, the company reported a net loss of $29.4 million, or $0.61 loss per diluted share. Excluding the special item, adjusted loss per diluted share was $0.58 for the quarter.

"Demand continues to improve as the recovery takes hold across our end-use markets, with our backlog up 35% sequentially and 106% year-over-year," stated Tony R Thene, president and CEO. "We continue to see signs of the aerospace recovery with lead times increasing despite any near-term uncertainties from the latest wave of COVID-19 cases."

Operating loss was $31.5 million compared to an operating loss of $89 million in the same period of the prior year (this figure included a goodwill impairment charge of $52.8 million). The improved results reflect higher sales as well as cost-savings actions taken in the fiscal year 2021. COVID-19 related costs, the special item excluded from adjusted operating loss in the current quarter, totalled $1.7 million.

www.carpentertechnology.com



Boeing satellite with over 1000 AM parts to increase capacity of communication services

Boeing has begun building the latest version of the Wideband Global SATCOM satellite system, WGS-11+, using advanced techniques like Additive Manufacturing to effectively integrate the latest commercial technology whilst enabling a five-year schedule that is expected to deliver results years faster than similar clean-sheet designs. The satellite system will feature over 1000 additively manufactured parts, with the majority being produced with aluminium alloy and titanium, as well as high-performance polymer.

"We're moving at record-breaking speed to deliver the unmatched resilience, efficiency, and throughput WGS-11+ offers our warfighters," stated Col Matt Spencer, Geosynchronous Earth Orbit and Polar Division Senior Material Leader at Space Systems Command. "Boeing's ability to rapidly integrate the latest commercial technology into our infrastructure gives us a competitive edge on the battlefield."

Troy Dawson, VP Government Satellite Systems, Boeing, added, "We're printing more than a thousand parts for WGS-11+, giving us the capability to introduce customisation in a way that improves system performance, without requiring extensive integration times or customised tooling. We understand how important speed is to the mission, that production speed translates to effectiveness against threats. As we continue to invest in our technology and processes, we know that a similarly capable satellite could be delivered even faster."

The WGS-11+, scheduled for delivery in 2024 (Courtesy Boeing)

When it joins the constellation of ten WGS satellites, WGS-11+ is expected to substantially increase the throughput capacity of essential communication services for the US government and its allies. It is scheduled for delivery in 2024.

www.boeing.com

Velo3D ships first Sapphire XC metal AM machine to aerospace customer

Velo3D, Inc, headquartered in Campbell, California, USA, has made the first delivery of its Sapphire® XC metal Additive Manufacturing machine. The XC, or 'Extra Capacity', is Velo3D's largest metal AM machine and is a scaled-up version of the company's Sapphire system, utilising the same Flow™ build preparation software, Assure™ quality control software, and Intelligent Fusion® manufacturing process.

The Sapphire XC is designed to enable the seamless transition of parts that were developed and qualified on the smaller Sapphire, the new machine reducing the cost of production by up to 75%. Sapphire XC also expands the use of Velo3D's technology to parts that are up to 400% larger in volume than the those possible with Sapphire.

"I believe that the Sapphire XC will quickly become the gold standard in advanced metal Additive Manufacturing," stated Benny Buller, Velo3D CEO and founder. "Because our customer is already utilising our end-to-end production solution, they can immediately and seamlessly move parts to Sapphire XC to achieve a phenomenal production rate increase. We made a huge effort to ensure that Sapphire XC uses the exact same manufacturing process as Sapphire. The ability to move production seamlessly between different products was considered impossible when we started Velo3D, but I am proud to declare that we have unlocked this ability for our customers and partners. It is a huge accomplishment — our biggest achievement of 2021."

Velo3D currently has a backlog of firm orders for seventeen additional Sapphire XC systems, as well as nineteen additional reservations. The company states that demand is primarily driven by the lower production costs that Sapphire XC can offer customers who have adopted the original Sapphire AM machines. The improvements are largely driven by new features and capabilities that include a larger build volume, additional lasers and faster non-contact recoater.

The Sapphire XC is able to additively manufacture a wide variety of materials that are often used in the production of mission-critical parts in the aviation, aerospace, defence, oil and gas, and energy industries. These include Inconel 718 & 625, Hastelloy® X, Hastelloy® C22, aluminium, Scalmalloy©, and titanium Ti6Al4V.

www.velo3d.com

Tekna order intake up 46%; announces consolidation of European metal powder production

Tekna Holding AS, Sherbrooke, Quebec, Canada, has reported an increase of 25% in materials revenues year on year in the fourth quarter of 2021. Annual materials order intake also rose 46% year on year, bringing the materials order backlog to CAD$10.2 million while the total order backlog stood at CAD$15.3 million.

"Tekna reported a solid order intake for materials in the fourth quarter, raising our order backlog to a record, amid strong demand from the aerospace industry," stated Luc Dionne, Tekna Holding's CEO. "The market outlook for Additive Manufacturing, which accounts for approximately 60% of Tekna's total revenue, remains positive, with demand in consumer electronics in China showing promising developments and sales in medical implants climbing towards pre-COVID levels."

Adjusted earnings before interest, taxes, depreciation and amortisation (EBITDA) in Q4 were reported at -CAD$3.3 million, compared to CAD$4 million in Q4 of 2020 in line with year-to-date forecasts. Total revenues were said to have decreased due to a decline in system sales year-on-year, caused by temporary COVID-related delays. The EBITDA was affected by lower systems revenue and high foreign commissioning costs arising from COVID restrictions.

European powder produciton

In January, Tekna announced the consolidation of its AM powder production in Europe at a new facility in Pont-de-Veyle, in eastern France, in an effort to allow the company to exist nearer to its European customers. In a move hoped to strengthen its supply chain resilience, the company signed a nine-year lease on the facility.

The 8,000 m^2 building is designed to hold up to 1,500 tons of powder manufacturing capacity for the production of nickel, aluminium and titanium powders. The facility also allows for further expansion of production capacity and for integrating printed electronics and energy storage activities at a later stage.

The plant is part of Tekna's ten-year business plan – launched in 2021 – to develop and accelerate growth in all three of its powder business segments. This facility enables the company to be closer to its portfolio of European customers, including previously announced and upcoming long-term supply agreements signed with major aerospace OEMs.

"This facility will be the centrepiece of a supply chain that is 100% European-based, ranging from feedstock procurement to manufacturing of advanced powders, and delivery to point-of-use, with fully traceable, closed-loop material recycling," stated Dionne.

www.tekna.com

Vertex to offer contract manufacturing with Xerox ElemX liquid metal

Vertex Manufacturing, a PrinterPrezz company, based in Cincinnati, Ohio, USA, is to install a new Xerox® ElemX™ Additive Manufacturing machine at its Cincinnati facility. The agreement with Xerox Elem Additive Solutions, part of Xerox, headquartered in Norwalk, Connecticut, USA, will allow Vertex to offer contract manufacturing services with Xerox's novel liquid metal AM technology.

Xerox's liquid metal process uses aluminium wire and requires no special facility modifications for operation. Unlike alternative AM technologies, there are no metal powders with ElemX and no need for PPE or other considerable safety measures. Engineered to bring simplicity to the supply chain process, ElemX is said to be the ideal option for spares, repairs and low-volume production parts.

By adding the ElemX to its existing fleet of advanced manufacturing technologies, Vertex states that it will become a valuable addition to the Xerox Elem Additive Solutions Manufacturing Partner Network.

"Our business is committed to delivering products and services that meet or exceed our customers' quality and schedule requirements," stated Tim Warden, vice president of sales & marketing at Vertex. "We decided to partner with Xerox because the ElemX technology gives us an added advantage to build parts faster and more reliably for our customers."

An ElemX AM machine from Xerox has been added to Vertex Manufacturing's facility in Cincinnati (Courtesy Xerox)

The ElemX AM machine was commercially introduced in February 2021 and, over the past year, Elem Additive Solutions has grown significantly, including opening an Additive Manufacturing Center of Excellence in Cary, North Carolina. The contract manufacturing agreement with Vertex is said to be another important milestone for Xerox.

Tali Rosman, Elem Additive General Manager and VP at Xerox, commented, "The relationship with Vertex enables our Elem Additive business to scale and support our customers better than before. Between the two organisations, there are decades of experience in advanced manufacturing, so we are thrilled to push the limits of this technology together."

Rosman continued, "ElemX takes all the benefits of 3D printing and makes it easier than ever before for manufacturers to use metal Additive Manufacturing. This is the next step in our journey, and we plan to continue advancing our vision for more resilient supply chains in 2022 working with partners like Vertex."

www.vertexmanufacturing.com
www.xerox.com
www.printerprezz.com

New proposed standard for managing cleanliness of metal powder for AM

ASTM International, Conshohocken, Pennsylvania, USA, reports that its Additive Manufacturing technologies committee (F42) is developing a proposed standard that will help to control the cleanliness of metal powder feedstock used in Additive Manufacturing processes, in an effort to ensure the quality of final AM components.

The proposed standard will reportedly help AM users to perform cleanliness assessments of unused and re-used powders. According to ASTM International member Aneta Chrostek-Mroz, powder handling and processing practices used in AM, particularly during powder reuse, may lead to deterioration of powder properties through the introduction of contamination. This can result in inclusions and defects in final components.

"The proposed standard will help manufacturers and users of metal powder feedstock used in Additive Manufacturing to identify suitable methods for detecting and quantifying different types of contamination," stated Chrostek-Mroz, research engineer at the MTC. "The guide will define and classify typical contamination that can be present within metal powder feedstock."

The committee invites interested parties to help develop the proposed standard (WK80171). Technical experts with experience in cleanliness assessment and/or have researched contamination of metal powder used in AM are particularly encouraged to become involved.

www.astm.org

Farsoon expands into the Middle East region through Modest Company partnership

Farsoon Technologies, headquartered in Changsha, Hunan, China, has announced a partnership with Dubai-based Modest Company LLC, under its new Additive Manufacturing division 3DTIV Tech, to represent Farsoon's metal and polymer Laser Beam Powder Bed Fusion (PBF-LB) AM machines for distribution, demonstration and service. Modest Company has served the United Arab Emirates (UAE) & Gulf Cooperation Council (GCC) industrial markets since 1975 and provides a range of products and services to businesses in the MENA region with clients in the oil & gas and construction industry. 3DTIV Tech will represent Farsoon in the UAE, Saudi Arabia, Qatar, Kuwait, Bahrain, Jordan, Oman, Tanzania and Kenya.

"As a company with diversified activities, we are pleased to offer Additive Manufacturing machines to our product line and aim to be one of the pioneers in providing Selective Laser Sintering and Melting systems for plastic and metal parts in the Gulf and East African regions," stated Ali Akbar Khimjee, Director of 3DTIV Tech, "With over ten years of research and development in the field, Farsoon Technologies is at the forefront in this dynamic industry and our partnership will present the region with innovative opportunities to a wide range of enterprises. This collaboration in the revolutionary 'Industry 4.0' as it's known, is sure to expand worldwide and we want to be a part of this journey."

Through the partnership, 3DTIV Tech will establish an Additive Manufacturing Demonstration Center in Dubai housing five Farsoon metal and plastic AM machines, including a Flight HT403P, HT403P, eForm, FS273M and FS121M. The aim of this AM centre is to provide a variety of functionalities for Mideast users including machine demonstration, benchmarking, training, as well as service & support. The 3DTIV Tech AM Center is expected to open to industrial customers in April 2022.

Vince Zhao, Global Channel Manager (AMEA) of Farsoon, commented, "We highly value the collaboration with Modest Company for their solid experience of offering industrial manufacturing solutions in Mideast and Eastern Africa. Being one of the most powerful economics in AMEA, we see great potential in Mideast and Eastern Africa additive market for a wide range of industrial applications driven by oil & gas, automotive, aerospace and researching institutions. With years of technology innovation and practice in Global industrial 3D printing market, Farsoon is confident to offer Mideast and Eastern Africa customers with our truly open, high-performance and cost-efficient Additive Manufacturing solutions."

en.farsoon.com
www.modest.ae

Meltio launches metal wire-based materials for DED process; names multiple sales partners

Meltio, Linares, Spain, is launching its own range of metal wire-based materials for Additive Manufacturing. The company now offers a welding wire range that includes stainless steel 316L, stainless steel 308L, mild steel ER70S, titanium 64 and nickel 718.

The company will continue to support the open materials platform of its wire-based Laser Metal Deposition (LMD) AM machines, with the range being compatible with third-party commodity welding wire. Meltio's LMD technology, also known as Directed Energy Deposition (DED), is compatible with most stainless steels, mild steels, tool steels, titanium alloys, and nickel alloys. In addition, invar, cobalt-chrome alloys, and precious metals like gold have been said to have shown great results in customer-led projects. Materials like copper, aluminium and refractories are still under development.

UK-based AM education project

Meltio has also entered a partnership with the UK-based CREATE Education Project, a specialist provider of Additive Manufacturing equipment for education, who will play a key role in the distribution and support of Meltio's metal AM machines in the UK education market.

The CREATE Education Project is committed to supporting educators, research, community outreach programmes and educational institutions to easily embed AM and technologies in STEAM (Science, Technology, Engineering, Arts, Mathematics) education, allowing educators to equip and empower student innovation and support the development of young people's skills for future careers.

Sales partners

Additive Technologies (AddiTec), Las Vegas, Nevada, USA, has been named the first official North American sales partner for Meltio. AddiTec will focus on building a supportive ecosystem for Meltio's technology within the USA and Canada.

3D Printer Solutions, an AM systems distributor located in Bergeijk, the Netherlands, was also announced as an official sales partner for the Benelux market. 3D Printer Solutions will seek to market Meltio products in the region via partnerships and driving business opportunities alongside technology centres, tooling machine companies, robotic integrators, academia and industry.

www.meltio3d.com
www.createeducation.com
www.additec.net
www.3dprintersolutions.nl

Metal Powder Emergence offers metal powders and consultancy services

Metal Powder Emergence Ltd (MPE), headquartered in London, UK, is a recently established business providing gas atomised metal powders for Additive Manufacturing as well as Metal Injection Moulding (MIM), Hot Isostatic Pressing (HIP) and cold/thermal spray applications.

Before founding MPE, Dr Gordon Kerr, the company's CEO, spent ten years at Phoenix Scientific Industries (PSI) where he worked with customers and collaborators developing VIM gas atomised powders for a range of applications and sectors. "My experience over the past ten years has shown that it's possible to supply high-quality additive metal powders at a cost which is more closely aligned with the client's needs," stated Kerr.

MPE is currently working with a key business partner to provide cost-effective, high-quality metal powders, which are manufactured in accordance with ISO 9001. The powders are melted under vacuum, which provides clean, free-flowing powders with high sphericity, vital for many AM processes.

"Generally, lead times are shorter compared to many other powder providers. All powders are requalified using 3rd party independent UK analytical service test houses which are also ISO 9001 compliant," added Kerr.

Established alloy powders based on aluminium, cobalt chrome, copper, titanium, nickel superalloys, stainless steels (316L, 17-4PH) are available, as well as the supply of bespoke novel alloy compositions. Technical and manufacturing consultancy is offered to assist in the development of powder alloy compositions tailored to meet clients' needs.

With a PhD in Chemistry from Heriot-Watt University in Scotland, Kerr has played a key role in European and UK funded projects with Innovate UK, Faraday and NATEP/ATI. He has previously held Managing Director positions and delivered growth within high-technology businesses, developing and implementing strategies to address various market and customer needs, as well as driving teams to common goals.

MPE can take a product from R&D scale to full-scale production manufacturing utilising marketing and sales expertise in order to meet a range of market needs. Kerr is primarily focused on developing novel AM materials for applications such as nanotechnology, responsive and smart materials for markets such as aerospace, marine, battery applications and space exploration. MPE has recently collaborated on new projects and applied for UK grant funding with a leading UK University in Materials Science and two well-established UK organisations.

www.metalpowderemergence.com ■

2oneLab launches new 2Create AM machine and 2Build software package

2oneLab GmbH, a recently established manufacturer of Additive Manufacturing machines headquartered in Darmstadt, Germany, has launched 2Create, the company's first Laser Beam Powder Bed Fusion (PBF-LB) metal AM machine. Designed specifically for small and medium-sized parts, the 2Create features a 250W laser with a 110 mm diameter x 100 mm high build plate. It can process a range of materials, including aluminium and titanium as well as nickel-, cobalt-, iron- and copper-base alloys.

The interface software for the 2Create is designed to enable easy setup and simple operation of the machine. At the same time, it offers a high degree of flexibility, with parameters such as laser power or spot size being adjustable during the process. This feature is said to be especially beneficial to users in research and development.

With an open concept design, the 2Create is compatible with metal powders from a number of powder manufacturers. "This flexibility, along with the machine's increased energy efficiency, drastically reduces the user's development costs," Markus Wolf, founder and CTO, told *Metal AM* magazine. "Whether you need to make implants, industrial parts or just for the flexibility of research and development, the 2Create can handle the job in a cost-effective, efficient and high-quality way."

2oneLab does not only focus on the development and manufacturing of AM hardware. The company's goal is to simplify the Additive Manufacturing workflow through the use of innovative software concepts, allowing the user to exploit the full potential of additive technologies. To this end, the company has also launched 2Build, its own CAM software package. 2Build is said to reduce preparation time, optimise build results and minimise post-processing.

"We see our software as an holistic solution to support the digital workflow as completely as possible. For example, in addition to classic features such as nesting, labelling and support creation, our software supports the planning of print production in the dental lab with the Production Manager Tool," added Ran Reznik, founder and CEO.

"In addition, we support the user in the development of new printing strategies. For this purpose, we have integrated a DoE [Design of Experiments] manager in the software. The entire test planning, according to statistical methods, can be carried out with this tool. The software analyses the density distribution of micrograph images of test patterns and calculates the optimal working point." concluded Reznik.

The new 2Create Additive Manufacturing machine from 2oneLab (Courtesy 2oneLab)

The 2Create is ideal for dental and R&D applications (Courtesy 2oneLab)

More information about the 2Create AM machine and 2Build software can be found on the company's website.

www.2onelab.com

Höganäs joins Additive Manufacturer Green Trade Association

The Additive Manufacturer Green Trade Association (AMGTA), an organisation positioned to promote the environmental benefits of AM, has been joined by Sweden's Höganäs AB as a founding member. Dutch and Belgian AM network Flam3D and the UK National Centre for Additive Manufacturing (NCAM) have also joined as participating members, bringing the total membership to forty.

Höganäs AB will serve alongside existing founding members Desktop Metal, Divergent Technologies, QC Laboratories, Sintavia, Stratasys, and Taiyo Nippon Sanso Corporation.

"I'm delighted to officially welcome aboard Höganäs, our new founding member, as well as each of our new participating member organisations," stated Sherry Handel, Executive Director of the AMGTA. "Our esteemed global trade consortium supports our mission and provides a solid foundation as we continue to grow and strategically invest in environmental sustainability research projects in Additive Manufacturing. I look forward to working with each of our members as we expand the AMGTA as the key industry resource committed to advancing sustainability in the AM industry."

www.hoganas.com

www.amgta.org

VDM Metals adds Powder 59 for demanding applications

VDM Metals GmbH, Werdohl, Germany, has announced VDM® Powder 59 as the latest addition to its Alloy 59 product line. Alloy 59 is one of the most frequently used nickel alloys for demanding applications in corrosive environments. In recent years, the fields of application of the alloy grew steadily, as new processes have been developed in the chemical and petrochemical industries.

With raw materials and energy sources becoming scarcer and more costly, but also due to ever more stringent environmental regulations, the demands on process parameters have increased. This has led to high operating temperatures, pressures and concentration of process media that can only be safely managed by high-alloy materials. VDM Powder 59 has particularly low concentrations of carbon and silicon and is characterised by excellent corrosion resistance.

Dr Christina Schmidt, Head of Powder Production, Research and Development, at VDM Metals, explained, "All elements of analysis are within the standard chemical composition of Alloy 59. The material is versatile in use in many chemical processes with oxidising and reducing media. Furthermore, this alloy is more resilient against localised attack in chloride containing media due to its high nickel, chromium and molybdenum concentrations."

"Additionally, based on a balanced chemical composition with a focus on workability, the powder shows excellent printing properties, which makes it possible to realise very complicated geometries without running into risks of crack formation," she continued. "First results of different corrosion tests show comparable results of printed parts with conventionally produced material."

Alloy 59 was initially developed for use in chemical processes and environmental technologies due to this material being able to work in the aggressive areas where nickel alloys of the so-called C series (for example, well-known Alloy C-276) differentiate from a large number of commercial nickel alloys, that are not resistant against prevailing conditions. The C series alloys typically exhibit the contents of 55 to 66 wt.% nickel, 16 to 23 wt.% chromium and 13 to 19 wt.% molybdenum. The high content of molybdenum gives them excellent corrosion resistance under reducing corrosive conditions and the high chromium content in oxidising media. Additions of tungsten may have an additional positive effect on the corrosion resistance, but they also impair the thermal stability.

Dr Schmidt added, "In the development of Alloy 59, VDM Metals further exploited this direction. The chromium content was raised by 7 wt.% to a content of 23 wt.% compared to the older C series, tungsten left out and the iron content reduced to approximately 1 wt.%. Molybdenum was kept at a high level of about 16 wt.%."

Dr Schmidt is confident that the new powder variant of the alloy will be a top seller, "From a technical point-of-view, we made sure that everything was ready for use in AM."

www.vdm-metals.com

Latest Alfa Romeo F1 race car sees metal AM in more critical applications

This year's Alfa Romeo F1 Team Orlen race car, the C42, is reported to feature around 150 metal additively manufactured components produced on MetalFAB AM machines from Additive Industries, Eindhoven, the Netherlands. As the team's metal Additive Manufacturing technology supplier since 2017, Additive Industries has been instrumental in the development and use of metal AM in the F1 car's design, seeing its use significantly increase over the years. Between 2020 and 2021, for example, consumption of AlSi10Mg and Ti64Gd23 almost doubled and Scalmalloy usage increased by a factor of four.

The Alfa Romeo F1 Team Orlen C42 is reported to feature around 150 metal AM components (Courtesy Alfa Romeo)

Although new regulation changes for the 2022 F1 season have resulted in fewer aerodynamic applications for AM parts this year, the C42 now includes more AM parts in critical applications. In total, the metal AM components correspond to a little over 1% of the total weight of the car.

www.additiveindustries.com
www.sauber-group.com

Metal AM magazine visited Sauber Motorsport in 2018, reporting on its partnership with Additive Industries, and how AM was being integrated into the company.

Read the Spring 2018 issue at www.metal-am.com

University of Bordeaux students develop novel WAAM process

Two students from France's University of Bordeaux, report that they have developed an innovative Wire Arc Additive Manufacturing (WAAM) process. The students, Rémi Thuillet-Méric and Théo Baldacchino, explain that by depositing only where needed, with as little as 2 mm of wire feedstock, substantial material savings can be achieved using this wire-based form of Directed Energy Deposition (DED). The team reportedly designed and built their metal AM machine from scratch, using recycled material and hardware from previous student projects.

The technology is said to have one key advantage that allows it to stand out in its sector - the work area theoretically allows the Additive Manufacturing of parts with infinite length. Even if the width and height of the parts are constrained by the dimensions of the machine, the length is not constrained.

The students remarked that the use of WAAM is growing in the naval, aeronautics and space industries. However, there are key challenges to be solved in order to increase the performance, specifically parts with curved shapes. These are difficult to manufacture with regular parallel layers without support because of an excessive overhang in certain regions. This new technology can solve the issue, states the students.

By leveraging the digital nature of AM, processing steps are reduced and finished products can be obtained much more quickly. The preparation and slicing time for Additive Manufacturing is equivalent to that of the most common cartesian axis machines, which allows it to be simple and quick to use, reducing the costs of preparing for AM. The particular kinematics allows it to produce hollow parts, with slopes, and uneven surfaces, all of which helps to reduce material costs, as required by industry, and also reduce environmental impact.

Students from the University of Bordeaux have developed an innovative WAAM process that can offer materials savings (Courtesy University of Bordeaux)

Tests were conducted to implement a path planning strategy, applicable to a large number of geometric shapes, to guarantee good quality of the final additively manufactured part. Since the arc start and stop phases generate noticeable defects in the final part, the optimisation criteria for tool path planning was the minimisation of arc start/stop phases. Additionally, gravity plays a key role and has to be considered for complex shape buildup. Several shapes were additively manufactured which included a hollow cube, W-profile and M-profile.

The initial idea for the project was generated during an internship with Dr Robin Kromer, Associate Professor in the Institute of Mechanical Engineering (I2M) at the University of Bordeaux. The students added that the overall objective is to present a ready-to-go Additive Manufacturing machine, with the in-situ monitoring and functional surface machining integration. They are aiming to minimise material waste and simplify manufacturing operations, opening this technology up to large-scale production of finished products.

www.u-bordeaux.com

Hunan Skyline Smart Material & Technology introduces metal powder for AM

Hunan Skyline Smart Material & Technology Co, Ltd, Yiyang, China, has announced the development of a <45μm aviation-grade spherical metal powder suitable for Additive Manufacturing applications. The news follows the company's adoption of plasma atomisation technology at its metal powder R&D facility.

Hunan Skyline offers a range of equipment for powdered materials preparation, sintering and heat treatment, as well as numerous metal powders. In addition to plasma technology, the company operates water, gas and rotary atomisers.

The company is located in the national high-tech zone of Yiyang City, in the Hunan province, and is reported to export its products to countries in Europe, the USA and Japan.

With the support of the science and technology commission of the Hong Kong Government, Hunan Skyline has cooperated with the Hong Kong Productivity Council in the construction of an Additive Manufacturing demonstration centre, helping develop an AM supply chain in the region.

www.skylinesmt.com

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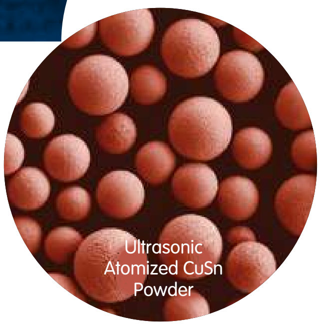

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Höganäs and Piab partner to increase sustainability of Additive Manufacturing

Staff at Höganäs and Piab, which have partnered to advance automation in AM (Courtesy Höganäs/Piab)

Sweden's Höganäs AB and Piab AB have formed a partnership to leverage their respective areas of expertise with the goal of advancing automation in Additive Manufacturing, aiming to increase the sustainability and efficiency of the process. Together, they are developing new solutions said to minimise metal powder waste while improving process efficiency and safety.

In many industrial AM applications, manual handling and loading of materials are still common practice. Piab and Höganäs are working together to introduce a new range of solutions that will enable customers to implement improved automation and optimised AM processes in order to save time, reduce waste, improve efficiency and secure a safer working environment.

Conveying metal powders poses specific challenges, such as the high bulk density and other material characteristics. Höganäs has extensive knowledge of metal powders and material containment solutions, which will be combined with Piab's existing products, such as the piFLOW® range of vacuum conveying solutions, to optimise both material handling processes and to develop new industrial-scale solutions. This also contributes to a higher level of operator safety.

Today, the partners are offering bespoke solutions for metal powder management which are based on existing piFLOW technology. These solutions are machine agnostic and can be used in multiple applications during the build process, including filling the build chamber with virgin or reclaimed metal powder, filling the sieve or hopper, or reclaiming the excess metal powder for reuse.

The goal of the new common development projects is to make the conveying of bulk metal powders even safer and easier, and to ensure that excess powder can be reused immediately, which reduces waste and helps to improve sustainability. This means that not only is waste disposal reduced, but also the amount of powder used is maximised, allowing manufacturers to make more with less. This new line of standardised technology will help further industrialise AM production and facilitate large scale manufacturing and industry 4.0 plans.

"Through this partnership, we can offer our customers better, more sustainable ways to work with their metal powders," explained Kennet Almkvist, President Customization Technologies, Höganäs. "It's also a big step forward in the industrialisation of these processes, as it removes elements of manual handling while optimising the amount of powder that's utilised in the printing. Piab has a long standing legacy in providing world-class automated conveying solutions and, together with our metal powder expertise, this range of products will make a real positive difference to our customers."

The solutions are said to cater to a range of Additive Manufacturing technologies, including Powder Bed Fusion (PBF) and Binder Jetting (BJT). This means they can be integrated into almost any metal powder-based production process.

"Höganäs is a true pioneer when it comes to metal powders," stated Floris Rouw, President Vacuum Conveying Division at Piab. "With this joint offering, customers can benefit from a combination of Höganäs' powder expertise and our conveying solutions that improve automation and, in turn, efficiency."

www.piab.com

www.hoganas.com

Infinite Flex releases pure copper powder for PBF-LB

Smart materials company Infinite Flex, with operations in Neu-Isenburg, Germany, and Taicang, China, has introduced its new Infinite Powder Cu 01, a pure copper powder suitable for use with Laser Beam Powder Bed Fusion (PBF-LB) machines. To date, the powder has been successfully tested on the EOS M290 and the TruPrint 1000 from Trumpf.

Pure copper is a popular metal in almost all branches of industry, thanks to its good electrical and thermal conductivity. Laser-based Additive Manufacturing has, however, traditionally struggled with adopting the element due to its refractory characteristics. Copper alloys such as CuCrZr and CuNiSiCr have been used in pure copper's place, but the conductivity of these alloys has only reached 70% and 40%, respectively, of pure copper's electrical conductivity.

Infinite Flex has introduced its first pure copper powder for Additive Manufacturing (Courtesy Infinite Flex)

By releasing Infinite Powder Cu 01, Infinite Flex hopes to enable the wider production of additively manufactured components with the high connectivity characteristics of pure copper, such as heat exchangers, induction coils and electronic components, on standard PBF-LB machines. Infinite Powder Cu 01 is now commercially available.

www.infinite-flex.de

Mimete enters metal powder distribution agreement with ICD Applied Technologies

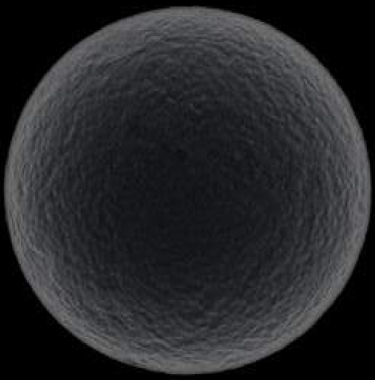
Mimete SrL, Osnago, Italy, has entered a distribution agreement with ICD Applied Technologies Ltd, Sheffield, UK, who will become Mimete's metal powder distribution partner in the UK and Ireland. Part of the Fomas Group, Mimete specialises in the production and analysis of metal powders.

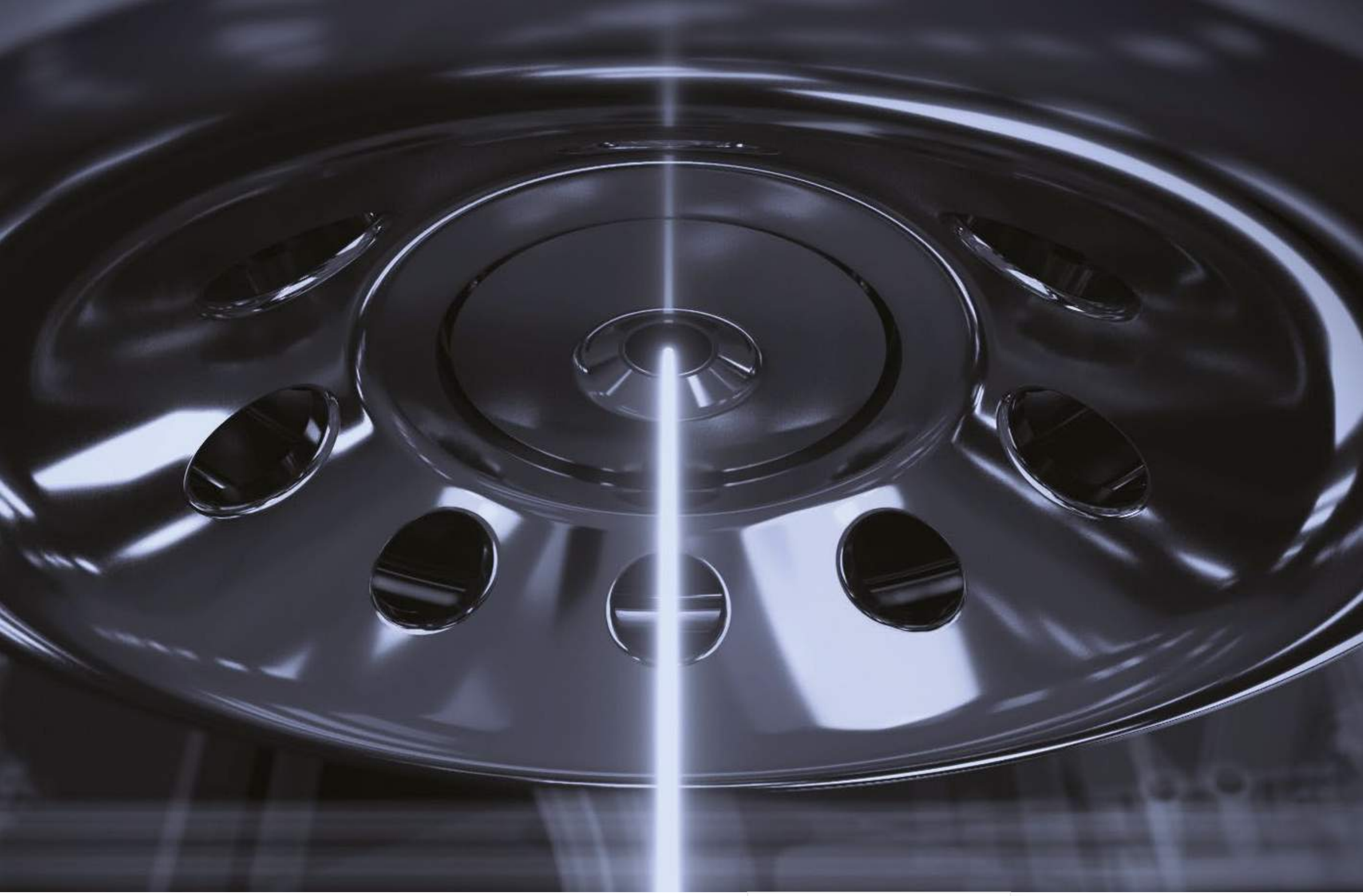
ICD Applied Technologies is focused on near net shape component manufacture using a range of powder metal and metal forming technologies including Additive Manufacturing. It is part of the ICD Group, an international company based in New York, USA, which is focused on the distribution and manufacture of specialist materials.

"We are very pleased to build further on our relationship with Mimete metal powders," commented Mathew Marsh, Director at ICD Applied Technologies. "This agreement allows for Mimete and ICD to grow and develop further the market for nickel, cobalt and iron based metal powders in the region."

Jacopo Guzzoni, Managing Director at Mimete, concluded, "With this agreement, Mimete enters the British and Irish market with a local based partner ensuring a faster and more thorough service to final customers."

www.mimete.com
www.icd-at.com





Materialise and Sigma Labs to improve QC for metal AM

Materialise, Leuven, Belgium, and Sigma Labs, Inc, Santa Fe, New Mexico, USA, have integrated the Materialise Control Platform (MCP) with Sigma Labs' PrintRite3D® sensor technology to create a solution that allows users to identify and correct build issues in the metal Additive Manufacturing process in real-time. With added control over their processes, the integration is expected to enable manufacturers to optimise metal AM processes for consistency and repeatability, key factors in scaling AM operations for serial production.

Metal AM has become more prominent in the manufacturing toolkit for companies in industries such as aerospace, medical device, automotive and energy to introduce more localised, customisable production. However, a lack of process robustness and repeatability is said to be holding back broader adoption for serial production, and the need for post-build inspection and quality assurance can result in higher costs when compared to traditional manufacturing methods. The new platform can be retrofitted to existing AM machines to improve manufacturing processes or offered as an add-on to new machines for metal AM.

The MCP is an embedded hardware solution that provides end-users more control over the AM process. By integrating the MCP with Sigma Labs' PrintRite3D sensor technology, the companies have created the possibility to identify quality issues and intervene to correct them in real-time. This is said to improve the productivity of metal AM and reduce scrap rates, paving the way for manufacturers to advance their operations and implement metal AM in serial production.

"The platform we've developed eliminates one of the most common roadblocks for manufacturers interested in using metal Additive Manufacturing for serial production," stated Bart van der Schueren, Materialise CTO. "The platform is open and flexible allowing manufacturers to take control of their specific processes to fit their unique applications. This makes it possible for customers to leverage their expertise and truly take advantage of the customisation and localisation benefits that AM provides."

In addition to the platform integration, Materialise and Sigma Labs will collaborate with end-users and machine producers to refine processes for their unique applications. The companies are seeking partners across industries who are interested in expanding their use of metal AM in serial production.

Materialise and Sigma Labs have integrated the Materialise Control Platform with PrintRite3D sensor technology (Courtesy Materialise)

Mark Ruport, president and CEO of Sigma Labs, commented, "I am very pleased with our long relationship with Materialise and the close collaboration between our engineering teams. We believe the combination of the Materialise Control Platform with Sigma's real-time melt pool monitoring, and analytics software has created a significant breakthrough in the Additive Manufacturing industry. I look forward to future opportunities to collaborate and find ways to continue to improve the quality and consistency of 3D metal printing as more companies go into production in the coming years."

www.materialise.com
www.sigmalabsinc.com

GKN Powder Metallurgy announces Diego Laurent as new CEO

GKN Powder Metallurgy has appointed Diego Laurent as its new Chief Executive Officer, with immediate effect. Peter Oberparleiter, who has been leading the company as CEO since 2012, is stepping down from his position after a long and successful career of more than thirty-four years with GKN.

Laurent joined GKN in 1993 and since then has held a number of senior finance positions within the GKN group in Brazil, Mexico and the USA. In 2013, he moved to the UK and was appointed Chief Financial Officer in 2018 to lead the Finance function for GKN Powder Metallurgy.

"I am very excited to lead our competent and forward-looking team. GKN Powder Metallurgy has been very successful in developing cutting-edge technologies and has become a pioneer in sustainable innovation and digital manufacturing. I look forward to developing the company further with the clear goal of shaping the future of Powder Metallurgy," stated Laurent.

Diego Laurent, new Chief Executive Officer at GKN Powder Metallurgy (Courtesy GKN Powder Metallurgy)

Laurent holds a bachelor's degree in economics, an MBA in finance, and a postgraduate qualification in production engineering.

www.gknpm.com

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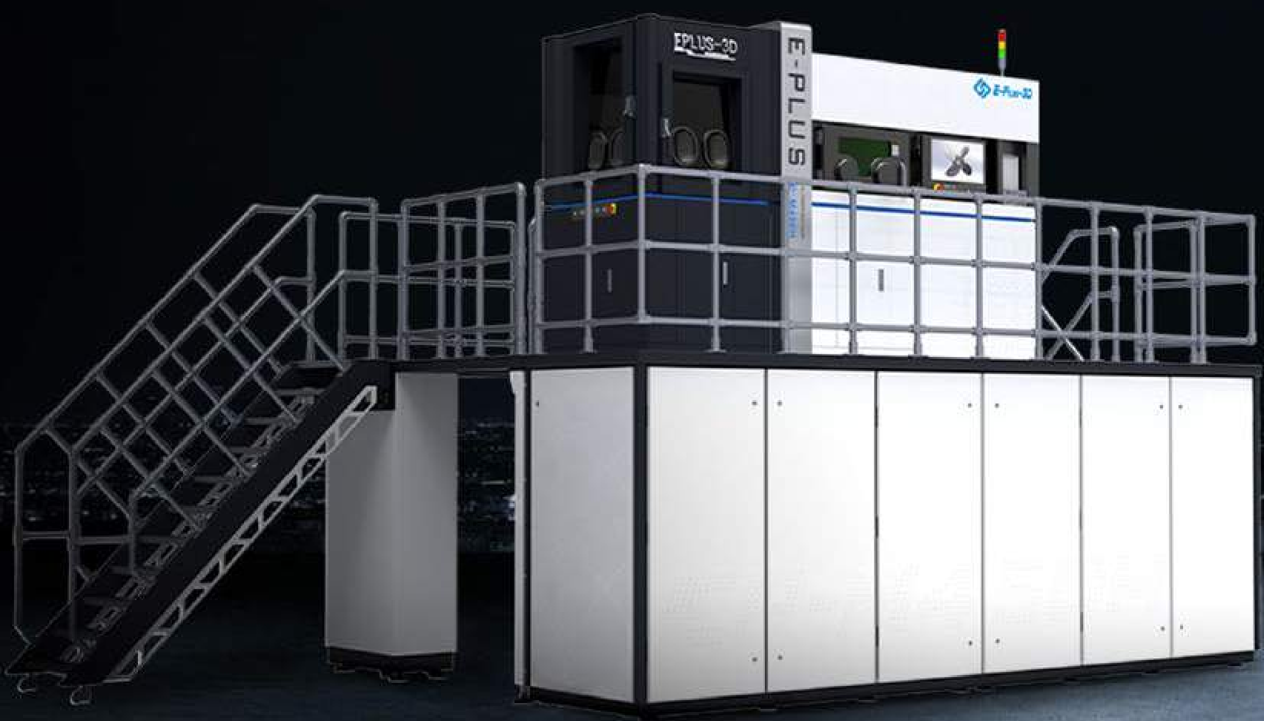

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Mimo Technik qualifies AlSi10Mg use for Boeing using SLM Solutions' AM machines

Manufacturing solutions provider Mimo Technik, headquartered in Carson, California, USA, has successfully met the material specifications performance for AlSi10Mg aluminium powder for Boeing, using metal Additive Manufacturing machines from SLM Solutions, Lübeck, Germany.

Mimo Technik credits SLM Solutions' open architecture philosophy for enabling the company to grow from designing and manufacturing motorsport and racing parts to producing and qualifying AM components for some of the aerospace industry's leading companies. Mimo Technik can now qualify materials, processes, and parts for aerospace flight faster than before. Thanks to AM technology, Mimo Technik's process is reported to be five to ten times more productive than the industry benchmark. The company's next goal is the qualification of high-strength aluminium alloys on SLM Solutions AM machines for Boeing.

"SLM Solutions technology enables us to create parts and design processes that are just not possible on any other platform," stated Jonathan Cohen, CEO & co-founder at Mimo Technik. "Their open parameters, open architecture system, and engineering spirit let us refine our processes and create parts to the highest standards in critical systems. From structures to electronics, the entire system is customizable to achieve the needed results. SLM's open architecture has been a key component in our success."

SLM Solutions' AM technology was the basis for Mimo Technik's switch from previously manufacturing polymers to metal Additive Manufacturing. The company began with one SLM® 280 in 2014, which has now evolved into an AM centre housing one SLM® 125, three SLM® 280s, and three SLM® 500s.

Dr Simon Merkt-Schippers, EVP of Product Management at SLM Solutions, commented, "This major qualification proves that Mimo Technik is a leading part manufacturer for the aerospace industry. It is almost unreal what Jonathan is getting out of our machines, resulting in incredible competitive advantages to Mimo Technik. On top of our open architecture, our extensive support for certified serial production comes along with the IQ, OQ, and PQ qualification process. These were key advantages for this joint success and for Mimo Technik's overall accelerated adaption of SLM technology for aerospace."

www.slm-solutions.com

www.mimotechnik.com

Ford to share insight into its Additive Manufacturing outlook at AMUG 2022

When the Additive Manufacturing community comes together once again at AMUG 2022 in Chicago, Illinois, USA, April 3–7, Ellen Lee, the Ford Motor Company's Technical Leader Additive Manufacturing Research, will deliver a much anticipated keynote on the company's AM developments. Speaking with *Metal AM* magazine's Kim Hayes, Lee previewed her upcoming keynote and shared her insights into where Ford, and indeed the wider mainstream automotive industry, currently is on the road to AM adoption.

Lee's keynote, 'Automotive Manufacturing to Additive Manufacturing: From History to the Future of Mobility,' both contrasts and complements the event's other keynote, to be delivered by Kevin Czinger of Divergent 3D and Czinger Vehicles, in which Czinger will speak in depth about his company's radically different approach to automotive production, the Divergent Adaptive Production System (DAPS™).

Having attended past AMUG conferences, Lee initially remarked on the sense of community at AMUG and explained what she is most looking forward to for the 2022 edition. "I have been attending AMUG for several years – except in 2020 and 2021, due to COVID. AMUG is unlike other conferences and trade shows in that there is a feeling of community; that we are all working together to advance AM. Because of that, it felt like the right place to deliver the message about automotive industry specific needs that must be addressed to be able to realise scalability."

"I will be discussing the impact that the automotive industry has had on the manufacturing technology landscape, including key events and innovations throughout history," Lee explained. "I'll give insight into how this influences the future of mobility and, in particular, what that means for potential AM adoption. I'll share the automotive point of view of what types of use cases and technology developments we should be focusing on now in order to find success in scaling to higher volumes in the future."

"Our technology drivers are different than those of the aerospace and medical industries, so delivering this keynote provides the opportunity to influence the industry direction. I'm looking forward to learning about the latest AM technologies and new innovative use cases, meeting people, and making connections," she stated.

Ellen Lee, Ford's Technical Leader Additive Manufacturing Research, will deliver a keynote on the company's AM outlook at AMUG 2022 (Courtesy Ford)

From polymer to metal Additive Manufacturing

Whilst Lee has a background in polymer engineering, her presentation will offer her perspective on the use of both metal and plastic AM in the automotive field. Commenting on the differences and overlaps between these two classes of material, and the different ways that they may be approached by automotive design engineers, Lee commented, "While my training is indeed in the polymer field, many aspects of understanding materials and manufacturing – such as the importance of process-structure-property-performance relationships – are analogous between the two areas. Similarly, both fields have many of the same overall challenges when we investigate a change from conventional, tooled production to AM production."

"Although polymer AM has been used extensively for prototyping, the primary materials used are not suitable for durable, end use automotive applications; on the other hand, while there are many examples of metal AM used for durable, end-use aerospace and medical applications, the cost and compatibility of these materials with our current metal alloys is a hurdle. The challenges that we need to navigate when considering AM for automotive production may differ between metals and polymers, but I would not characterise one being treated with more or less apprehension than the other."

A colleague inspects a range of additively manufactured parts produced by Ford (Courtesy Ford)

The old and the new in automotive

With both AMUG keynotes focusing on the automotive industry this year, one cannot help but see this as a perfect play off against the new, disruptive, high-performance auto maker and the established, over 100-year-old automotive mass producer. Of course, the auto industry has been innovating incrementally for many decades, but recently, with the rise of electric vehicles and ever more stringent emissions targets, it seems there has been more of a drive for innovation, but to what extent has AM played a part in this? Lee shared her thoughts on this:

"I agree that having keynotes from both Ford and Divergent3D/ Czinger Vehicles is a terrific opportunity for the AMUG attendees to understand the needs and challenges in the automotive industry between performance and democratisation. However, I wouldn't characterise it in exactly the same way. While Ford is focused on democratisation of technologies for every person, we have long used lower volume and performance platforms for disruptive innovation, not just incremental solutions."

"We often implement new innovative technologies for motorsports or in a luxury vehicle where customers desire specific performance; then work to scale the technologies to higher volume platforms," she explained. "With these new automotive start-ups that focus on high performance vehicles at ultra-low volumes, theirs is an extension of the same approach. Most technologies in your car today started out in a race car. As we move towards more AVs and EVs, as well as with increased consumer desire for more customisation, I do expect that AM will be a key enabler for even faster innovation."

Ellen Lee with members of the Ford Additive Manufacturing Research team (Courtesy Ford)

Breaking into a heavily controlled industry

When it comes to replacing traditional manufacturing processes with AM, there is naturally some caution from an industry that has such rigorous quality and process control standards. Automotive makers have long-established and well-trusted supply chains and the idea of replacing casting, machining, PM, MIM, etc, with AM for high volumes of structural and load bearing components is a big step.

"You are absolutely correct," stated Lee. "In order to successfully implement AM for a series production application, not only does it need to meet the technical feasibility for all performance and durability requirements, and meet manufacturing process capability for quality, but it also needs to do so with a good value proposition. The business case looks different for AM than for conventional tooled production, and must take into account all the unique benefits from AM. But you've touched on a key point in that we have a trusted and very complex supply chain network. However, many of our trusted tier suppliers in the automotive industry are not experienced in AM technologies; while the contract manufacturers who know AM best are not a part of our current supply


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www.materials-solutions.com

chain and are unfamiliar with the automotive industry needs. During this critical time, we need to tackle this challenge from both sides to develop our ideal automotive AM supply base."

Touching on that key point of trust in a supply chain for auto makers, AM standards will hopefully go on to play an essential part in establishing and maintaining that trust. We asked Lee how active Ford is in the development of AM automotive standards.

"AM standards are essential in getting to scaled production for any industry vertical. They ensure that things are done in a safe, reliable, and consistent manner. When we need to compare the performance of something, standards tell us how to make, measure, or evaluate that product against equivalent metrics. Only when these standards are in place can we have confidence that we can meet specific targets. Ford has been quite active in this space."

"We work closely with colleagues from GM and Stellantis through USCAR (the United States Council for Automotive Research) and are currently developing automotive specific standards for AM. The three companies have also been collaborating with UL (formerly Underwriters Laboratories) to advise on standards for certification of AM polymers. Finally, I am an officer on the ASTM F42 Executive Committee for AM so that I can provide a voice from the automotive industry; and have worked with the ASTM AM Center of Excellence partners in standards development for powder re-use and recycling."

The potential for real volume production

Looking ahead to when the industry might reach 'real' volume production, we must question how supply chains will develop. In terms of the 'chicken and the egg,' it's not possible to ramp up usage of AM if the supply chain doesn't have the capacity, but end-users develop a complete facility for volume production in house. Are there currently any signs that this supply chain is taking shape?

"The 'chicken and egg' challenge is not unique to AM. It's a common one in the development of any new technology that requires significant infrastructure and value chain development," answered Lee.

"There are signs that this is happening somewhat organically; although our specific needs are different among automotive, aerospace, medical, and consumer industries, there is enough overlap that contract manufacturers are able to support us all as capacity needs ramp up. As AM usage grows, the supply chain will mature and have more specialised capabilities," she concluded.

www.ford.com
www.amug.com

Fraunhofer ILT and Trumpf collaborate to offer DED solutions to industry

The Fraunhofer Institute for Laser Technology (ILT), Aachen, Germany, and Trumpf, Ditzingen, Germany, have signed a cooperation agreement to collaborate more closely in the field of Laser Material Deposition (LMD), a form of Directed Energy Deposition (DED), and accelerate the transfer of the technology to industry.

Fraunhofer and Trump will advance LMT technology (Courtesy Trumpf)

"When we transfer our technologies to industrial applications, our customers are increasingly focusing on the questions of systems engineering implementation, especially with regard to the availability, stability and suitability of the components," stated Dr Thomas Schopphoven, head of the Laser Material Deposition Competence Area at Fraunhofer ILT.

These are reportedly the standard questions that Dr Thomas Schopphoven and his team at Fraunhofer ILT are asked by interested customers from the industry. This is where the cooperation with Trumpf will come into play, due to the company's experience in LMD machines.

Marco Göbel, Industry Manager at Trumpf, commented, "Thanks to the close cooperation with Fraunhofer ILT, we can offer solutions for the entire production chain from a single source. By combining our system technology – optimised for industrial use – with processes adapted or specially developed for this purpose, we help customers all over the world benefit from these innovations."

For process and application development in Aachen, Trumpf will provide the Fraunhofer ILT team with state-of-the-art laser-based DED machines that have various optical systems and powder feed nozzles.

"In this way, we research our processes directly on industrially relevant systems. This enables us to transfer our research into customer applications particularly efficiently," added Dr Schopphoven.

The technology will be installed at the beginning of this year and available for the first tests in the spring. Numerous promising applications are already said to be in sight, such as the economical coating of passenger car brake discs or the wear and corrosion protection of hydraulic cylinders.

www.ilt.fraunhofer.de
www.trumpf.com

Authentise acquires Elements Technology to bring data-driven flexibility to manufacturing

Authentise, Philadelphia, Pennsylvania, USA, reports that it has acquired all the assets of UK-based Elements Technology, a provider of self-serve workflow tools for manufacturing. The acquisition will enable customers to access connected workflow management solutions used by leading Additive Manufacturing companies to manage their lot-size one operations efficiently. As part of the transaction, Elements' team will join Authentise.

"Elements is the perfect addition to the Authentise portfolio," stated Andre Wegner, CEO of Authentise. "Like Authentise, Elements have been laser focused providing manufacturing operations with the flexibility they need in the post-pandemic world with the efficiency that data enables in the 21st century."

"Elements provides customers with a unique self-serve tool for all types of manufacturing operations, to quickly create, capture and access repeatable shop floor processes," continued Wegner. "Delivering intelligent production planning and scheduling, and real time views of production, customers can track orders, like they're paying for coffee. These exciting services will become a key part of the combined Authentise portfolio."

"Our goal together is to bring flexibility and responsiveness benefits like these, typically associated with Additive Manufacturing, to a broader manufacturing audience. With our diverse experiences we believe we will be able to rapidly accelerate towards our joint mission of delivering end-to-end transparency, reliability, and efficiency to manufacturing operations using data. We're delighted to welcome the Elements team and customers on board," Wegner added.

Joe Handsaker, CEO of Elements Technology, commented, "The real story of Industry 4.0 has yet to be written. The last twenty years have been wasted focusing on predictive maintenance and analytics, which have yielded very little Return on Investment. It's time to refocus on what's core to manufacturing: the worker. Supporting them with data and modern tools gives us more context in manufacturing and allows us to drive better quality, insight, and completely new business models. If nothing else, the pandemic has shown that a radical rethink of the way things are made and delivered is necessary. We're delighted to have found a partner that understands that and are excited to build a better future, together."

www.elementstechnology.com
www.authentise.com

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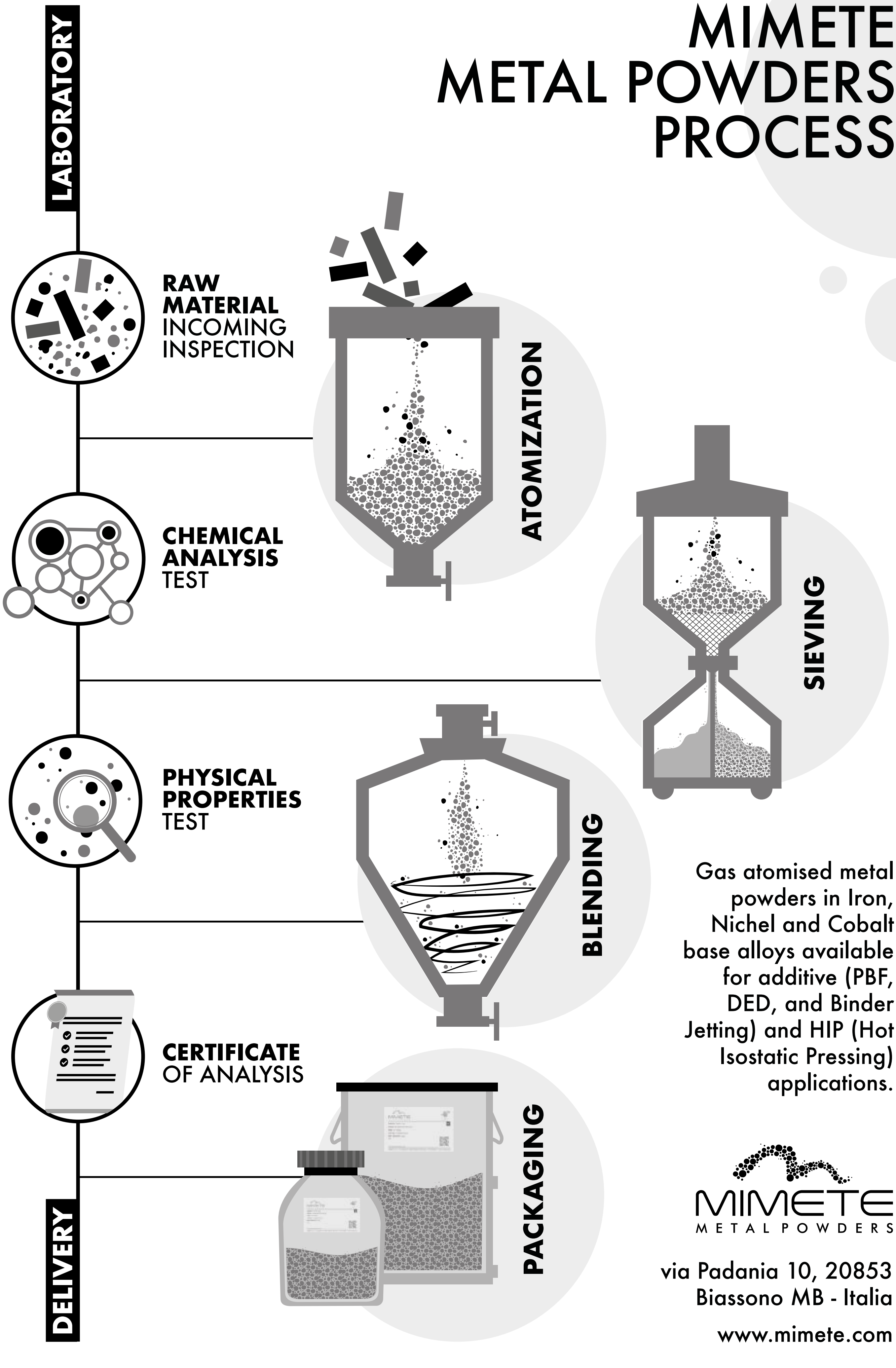

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Greg Mark departs Markforged, new corporate headquarters announced

Markforged, Watertown, Massachusetts, USA, reports that Greg Mark, the company's Director and co-founder, has resigned his positions as member of the board of directors and as an employee, effective December 29, 2021.

Shai Terem, president and CEO at Markforged, stated, "We are extremely grateful for Greg's significant contributions to Markforged since founding the company in 2013. Greg established a truly innovative company with revolutionary technology that will continue to thrive as we pursue our mission to reinvent manufacturing and enable our manufacturing customers to move to robust production at the point of need. We wish Greg success in his future endeavours."

The company has also announced its plans to relocate its global headquarters to Waltham, Massachusetts, a move which will unite Markforged employees who have been working from two different facilities in Watertown in one location at 60 Tower Road, and nearly double the company's footprint in an effort to enable further growth.

The new headquarters, expected to be completed in Q3 2022, will occupy 11,148 m^2 (120,000 ft^2) across four floors and can accommodate over 500 team members and features an interactive product showroom that will create a collaborative environment for Markforged employees. The company also hopes to build engineering facilities and laboratories for its teams to continue delivering the accelerated and innovative product roadmap around hardware, software, and consumables that make up the Digital Forge.

Terem added, "I am very proud of our team's successes over the last year and the momentum that we're building. We continue to grow and accelerate our product roadmap, and are seeing demand for our newest products, like the FX20. Our rapidly growing team has nearly doubled in 2021, and this headquarters relocation is a natural next step that will enable us to create a state-of-the-art space for our employees, our partners, and our customers to experience what Markforged is all about."

Markforged Director and co-founder, Greg Mark, has departed the company (Courtesy Markforged)

Additionally, as Markforged looks to meet demands for its products, it will also nearly double the size of its Billerica, Massachusetts, based filament manufacturing facility in 2022 by adding around 2, 000 m^2 (22,000 ft^2), bringing the total footprint to some 4,300 m^2 (46,000 ft^2). Markforged anticipates the completion of this expansion by the end of next year.

"As we introduce new products like the FX20 to the marketplace, we are excited to invest in the company to meet customer demand," commented Matt Gannon, VP, Operations at Markforged. "This new space will better position Markforged to scale our consumables processes and lay the foundation for new materials development."

www.markforged.com

Hyperion to pursue US listing and name change to IperionX Limited

Hyperion Materials & Technologies based in Columbus, Ohio, USA, reports that it intends to file a registration statement on Form 20-F to register its ordinary shares with the United States Securities and Exchange Commission (SEC), subject to review. A Form 20-F, once declared effective by the SEC, allows certain non-US issuers to register securities with the SEC pursuant to applicable US securities laws. If approved, the company's registration of ordinary shares would allow American depositary shares representing ordinary shares of the company to be listed on a national securities exchange in the US.

A listing on a national securities exchange in the US is expected to enhance the visibility and accessibility of Hyperion to the US market of retail and institutional investors and enable new and existing US investors to trade Hyperion's American depositary shares in US dollars and during normal US trading hours.

As a result of Hyperion's proposed US listing, the company will seek shareholder approval to change its name to IperionX Limited. This name change is said to be the result of a potential conflict in the US with the company's existing name that has been recently identified. A notice of general meeting will be sent to shareholders shortly.

Anastasios Arima, Chief Executive Officer and Managing Director, stated, "The proposed listing is expected to create greater awareness of our US-focused critical minerals and metals technologies in the United States, providing exposure to enormous investor demand in a market which has a deep understanding for advanced technologies that support global decarbonisation efforts, such as Hyperion's low carbon titanium metal technologies. We believe that access to a much larger pool of capital will provide the potential for increased liquidity and enhanced value for our shareholders."

www.hyperionmt.com

RE3DTECH acquired by Core Industrial Partners

RE3DTECH, an Additive Manufacturing service bureau based in Grayslake, Illinois, USA, has announced its acquisition by private equity firm Core Industrial Partners. The move is anticipated to unlock further resources for the company, allowing it to improve services and further expand production capacity.

"RE3DTECH was founded with the mission to provide our customers with customised solutions utilising the latest, state-of-the-art technologies," stated Jim Teuber, president & CEO of RE3DTECH. "Our partnership with Core will help unlock the resources necessary to continue investing in cutting-edge capabilities and further enhance our customer value proposition."

The company has a range of in-house manufacturing, including polymer and metal Additive Manufacturing, finishing, quality control and assembly. Utilising machines from HP, Markforged and SLM Solutions, RE3DTECH offers Binder Jetting (BJT) and Laser Beam Powder Bed Fusion (PBF-LB) technologies to manufacture production-grade parts for end markets including aerospace & defence, industrial, automotive and medical.

"Our investment in RE3DTECH represents an expansion of our thesis within the Additive Manufacturing sector to address the growing market for high-volume production needs," commented John May, Managing Partner of Core. "We believe Core's sector expertise and resources will prove highly impactful in accelerating the company's growth, both organically and through complementary acquisitions."


RE3DTECH has a range of in-house manufacturing, including polymer and metal Additive Manufacturing (Courtesy Core Industrial Partners)

Matthew Puglisi, Core partner, concluded, "RE3DTECH's strong growth since inception is the direct result of the company's combination of talented employees, breadth of Additive Manufacturing technologies, design & engineering capabilities, and quick turnaround times to provide a differentiated experience to its customers. We look forward to building upon the company's solid foundation to further expand its service offering and geographic reach."

www.coreipfund.com
www.re3dtech.com

Trumpf Additive Manufacturing Italia forms from previous Sisma joint venture

Trumpf, Ditzingen, Germany, has taken over full ownership of the joint venture Trumpf Sisma srl from its Italian partner Sisma spa. The business will be renamed Trumpf Additive Manufacturing Italia srl, but will remain at its current headquarters in Schio, Italy.

The company currently has around sixty employees who work in the development and production of metal Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machines for the industrial, dental and medical markets.

With the sale of the joint venture and its own PBF-LB division, Sisma has expressed plans to focus on the jewellery and fashion industries in the future, and distribute PBF-LB machines from Trumpf for these markets. The two companies did not provide further details on the agreement.

www.sisma.com
www.trumpf.com

Fehrmann Alloys adds Mahendran Reddy and Stefan Ritt to management team

Mahendran Reddy (left) and Stefan Ritt (right) (Courtesy Fehrmann Alloys)

Fehrmann Alloys GmbH & Co KG, Hamburg, Germany, has appointed Mahendran Reddy to VP – Global Ecosystem Development and Stefan Ritt to VP – Market Development and Communication.

Reddy is recognised for his establishment of the National Additive Manufacturing Innovation Cluster (NAMIC) in Singapore. As Business Development Director, he was involved in driving the adoption of Additive Manufacturing in the Asian industry and expanding the AM ecosystem thereby initiating joint research projects between industry & academia and the NAMIC Global AM Summit series and outreach programmes.

Since joining Fehrmann in January, Reddy has released a technical article on the potential of innovative high-performance aluminium alloy in an Indian aluminium trade journal and provided insights into the AM ecosystem in Singapore during a free online event as part of the 3D Printing Tuesday organised by 3D Printing North Network. He was also one of the distinguished speakers at ALCircle EXPO 2022, where he addressed the aluminium industry.

Stefan Ritt was appointed to his new role at Fehrmann Tech Group in February, having previously worked as an AM expert in equipment technology, software, teaching and standardisation. Whilst at SLM Group, Ritt coordinated the global marketing activities and presented its first Laser Beam Powder Bed Fusion AM machine at an AMUG conference. As European Managing Director of SPEE3D, he introduced another cold spray metal AM technology to the market and, in his role as International Business Advisor, he supported clients in expanding global AM and prototyping activities.

www.fehrmann.tech

Sennheiser turns to Additive Manufacturing for its IE 600 earphones

The newly released IE 600 earphones from Sennheiser electronic GmbH & Co KG, Wedemark, Germany, feature housings produced by metal Additive Manufacturing. The purpose of the metal AM housings, which are hand-finished for aesthetics, is to protect the delicate transducer and enable the production of complex chambers and channels requiring no milling after production. Post-processing operations include steel shot blasting, polishing and surface treatment, resulting in an extremely durable and wear-resistant component.

The housings, manufactured by Heraeus AMLOY Technologies GmbH on a TruPrint 2000 Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing machine from Trumpf, are built from Heraeus's Amloy ZR01. This amorphous zirconium alloy was selected by Sennheiser for its durability – it's reputedly tougher than high-performance steel – in combination with its aesthetic surface quality. Previously, this advanced material was trialled by NASA for ice cutting on one of Jupiter's moons.

"Working at the cutting edge of technology is super exciting and knowing that we work on the same materials as the most demanding organisations in the world use – like NASA – is an extremely exciting opportunity," stated Jermo Köhnke, Product Manager at Sennheiser. "It always makes your heart jump if you're an engineer – or just a tech fan."

Heraeus Amloy ZR01 is said to have triple the hardness and flexural strength of high-performance steel. Shock-frozen during manufacturing, amorphous metals never have a chance to form a crystalline structure like conventional metals.

Jürgen Wachter commented, "Amorphous alloys are an extraordinary new class of materials. Our high-tech AMLOY ZR01 is used in components for aerospace and MedTech applications that require ultra-high precision and robustness. We are proud that Sennheiser evaluated our space-grade amorphous alloy and decided to use it for the IE 600."

www.sennheiser.com

Sennheiser has utilised Additive Manufacturing in the production of its IE 600 earphone (Courtesy Sennheiser)

The additively manufactured casings for the IE 600 earphones (Courtesy Sennheiser)

Siemens Energy and Zeiss launch MakerVerse digital platform for on-demand AM services

Zeiss Group, Oberkochen, Germany, and Siemens Energy, Munich, Germany, supported by venture capital fund 9.5 Ventures, have launched MakerVerse, a new digital platform for on-demand Additive Manufacturing services. The venture is expected to act as a one-stop fulfilment centre that will connect industrial clients to a global network of certified Additive Manufacturing suppliers.

MakerVerse offers instant quoting, automated manufacturability checks, streamlined supplier and quality management, and industrial-level quality assurance. The platform is intended to eventually cover the full technological service spectrum, starting with core AM technologies and expanding into further on-demand technologies such as CNC and Injection Moulding in the future.

MakerVerse will be based in Berlin, with its initial focus on the European market. The public launch of the platform is planned for early mid-2022.

www.siemens-energy.com
www.zeiss.com
www.maker-verse.com


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solukon.de

Fritsch updates its laser particle sizer range

Fritsch GmbH's Milling and Sizing division, Idar-Oberstein, Germany, has expanded the particle size range of its ANALYSETTE 22 NeXT to include Micro (.005-1500 μm) and Nano (.001-3800 μm) sizers.

The latest generation of ANALYSETTE 22 NeXT operates like the other sizers in this series, without any additional light source required due to the use of a single laser. This means that the sizers can record an entire measuring range in a single scan, which can be completed in under a minute using wet dispersion.

The dispersion unit of the sizer is designed for long, low-maintenance service life. Without valves and moveable seals in the sample circulation system, no space is left empty, which means no sample material can accumulate and settle. A centrifugal pump with individually adjustable speed is expected to ensure stable measuring in the dispersion unit; to measure samples tending to agglomerate, a user can add an ultrasonic box to the sample circuit.

Those interested in these products can send a sample measurement to the company for analysis protocol. Further information is available via the company website.

www.fritsch-international.com ■■■

Fathom Digital Manufacturing listed on NYSE

On-demand digital manufacturing service provider Fathom Digital Manufacturing Corp, Hartland, Wisconsin, USA, began trading on the New York Stock Exchange (NYSE) as FATH on December 27, 2021, after the completion of its business combination with Altimar Acquisition Corp II. Prior to the combination, Fathom was a privately held portfolio company of CORE Industrial Partners, a Chicago, Illinois-based private equity firm focused on investing in and growing middle-market manufacturing, industrial technology and industrial services businesses. CORE will remain the largest shareholder in the combined business.

Across its twelve facilities, Fathom utilises in-house Additive Manufacturing technologies, CNC machining, Metal Injection Moulding (MIM) and tooling, sheet metal fabrication and design and engineering to serve clients in the technology, defence, aerospace, medical, automotive and IOT sectors.

"We are taking this step because we are a strong, profitable company, and believe our NYSE listing will accelerate Fathom's growth, both organically and inorganically, by using our stock as a currency to advance our M&A strategy and investing in promising new technologies across the industry," stated Ryan Martin, CEO. "These new technologies will enable us to serve our target markets with greater efficiency and responsiveness than ever before. Our broad capabilities from rapid prototyping to low- to mid-volume production, proprietary software suite, engineering expertise and comprehensive support system are competitive advantages we expect will enable us to continue executing our strategic plan and delivering strong profitable growth."

John May, founder and Managing Partner of CORE, added, "With the completion of this transaction, Fathom has solidified its position at the forefront of the fast-growing on-demand digital manufacturing sector. The company's unique on-demand platform and diverse offerings serve a broad variety of customers, ranging from the Fortune 500 to high-growth disruptive startups, and are perfectly suited to the challenges and opportunities facing manufacturers today. We are extremely proud of the incredible growth and innovation the Fathom team has achieved over the past three years since we initially partnered with the company, and we're excited to remain Fathom's largest investor. We are confident Fathom's solid foundation will enable the company to achieve further success in the public markets."

Fathom will continue to be led by Ryan Martin, Chief Financial Officer Mark Frost, Chief Commercial Officer Rich Stump, and chairman of the board TJ Chung.

www.fathommfg.com ■■■

AM is key to Kennametal's award-winning stator bore tool

Kennametal's award-winning AM stator bore tool weighs 7.3 kg (Courtesy Kennametal)

Kennametal Inc., Pittsburgh, Pennsylvania, USA, has introduced a next-generation additively manufactured stator bore tool, weighing 7.3 kg, for the machining of aluminium engine housings for electric vehicles. The newly redesigned tool recently won *MM MaschinenMarkt*'s Best of Industry Award in the Production and Manufacturing category, based on votes by readers and industry experts.

This version of the tool features a newly designed arm structure, and a larger centre tube made of carbon fibre. Capable of machining three diameters in one operation, the stator bore tool is said to ensure the alignment and concentricity of the machined surfaces whilst reducing the cycle time. The tool enables a faster tool change and spin-up even on less powerful machines. The surface specifications and component tolerances are achieved without constraints.

Hassle-free chip removal is said to be ensured by means of airfoil-shaped arms that enable precise and powerful coolant supply to the cutting edges and guide pads. This would be difficult or impossible to economically produce with traditional manufacturing, but AM has enabled Kennametal to realise complex internal features. Additionally, the the company's RIQ reaming system features easy diameter adjustment and a trouble-free setup of new inserts.

"As our automotive customers expand their offerings of hybrid and electric vehicles, we continue to respond to their need for lighter weight tooling solutions," stated Ingo Grillenberger, Product Manager, Kennametal. "By leveraging advanced manufacturing techniques like 3D printing, we've reduced weight a further 20% over the first-generation tool, while improving chip control and increasing tool rigidity – innovations that help our customers machine faster and more efficiently."

www.kennametal.com

Desktop Metal qualifies commercially pure copper and high-strength DM HH Stainless Steel for Production System

Desktop Metal, Boston, Massachusetts, USA, has qualified C10300, commercially pure copper with over 99.95% purity, for use on the Production System™, which utilises the company's Single Pass Jetting™ (SPJ), a form of Binder Jetting (BJT) technology. The company also announced that it has developed and qualified DM HH Stainless Steel (DM HH-SS) for use in the same platform.

Due to copper's excellent thermal and electric conductivity, its addition to the range of materials qualified for the Production System will enable the manufacture of high-performance parts at scale across a broad variety of industries, including automotive, aerospace and electronics.

"Copper has been a highly requested material from many of our customers and prospects, and has applications spanning a broad variety of industries, from thermal hardware found in air and liquid cooling systems to conformally cooled coils for transmission of high frequency currents," stated Jonah Myerberg, co-founder and CTO. "We are excited to be able to expand our extensive Production System materials portfolio to support customers looking to 3D print electrically and thermally conductive components at scale and at a fraction of the cost of conventional manufacturing methods."

DM HH-SS is a custom, heat treatable-alloy that combines the tensile strength, ductility, and corrosion resistance of 13-8 PH stainless steel with hardness comparable to low-alloy steels, such as 4140. These attributes make DM HH-SS well suited to companies looking to eliminate the use of low-alloy steels, which require a subsequent plating step for applications needing corrosion protection. DM HH-SS is also a good material for conformally cooled injection tool core and cavity applications, where millions of injection strokes per year are required.

"Our materials science team is working diligently to develop innovative materials that meet the demanding applications needs of our customers in a cost-effective way," added Myerberg. "DM HH-SS is a compelling alternative to 17-4 PH stainless steel that improves upon its mechanical properties while maintaining corrosion resistance, making it suitable for critical components that previously required the use of low-alloy steels for their high hardness and strength. The Production System allows customers to go to market at scale with this material and eliminate operations, such as plating, which can create supply chain complexity and also be harmful to the environment."

www.desktopmetal.com

Velo3D qualifies new superalloy for use in Sapphire AM machines

Velo3D, Inc, headquartered in Campbell, California, USA, has qualified the nickel-base superalloy powder Amperprint® 0233 Haynes® 282® for use in its Sapphire® range of metal Additive Manufacturing machines. The powder was produced by Höganäs AB under licence from Haynes International, Inc, and is designed for high creep strength, thermal stability, weldability, and fabricability uncommon in other alloys. The material is said to be ideal for high-temperature structural applications like energy generation, gas turbines, and space launch vehicles to build parts like heat exchangers, combustors, nozzles, combustion liners, rocket engines, and shrouded impellers.

The first Sapphire AM machine utilising the Amperprint 0233 Haynes 282 powder will be operated by Duncan Machine Products (DMP), a contract manufacturer based in Duncan, Oklahoma, USA. The machine will be the seventh in DMP's fleet of Velo3D Sapphire AM machines.

"Our goal at Velo3D is to enable engineers to build the parts they want without compromising on the design or quality," commented Benny Buller, Velo3D CEO and founder. "Qualifying new powdered metals, like Amperprint 0233 Haynes 282, for use in our end-to-end solution further expands what's possible with our Additive Manufacturing technology. Our partners at Höganäs provide materials of the highest quality and I look forward to seeing what our customers build using this amazing alloy."

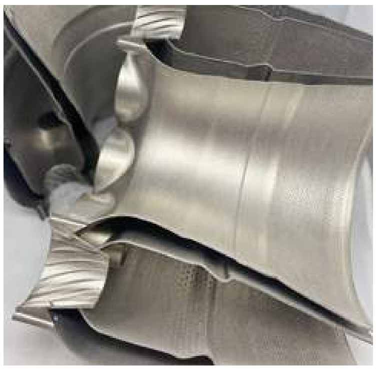
Powdered nickel-base superalloys, such as Amperprint 0233 Haynes 282, are often used to additively manufacture parts for use in high-temperature applications due to the alloy's resistance to cracking and its ability to operate at near-melting-point temperatures. This tolerance allows parts produced with the alloy to be used in vacuum, plasma, and other demanding applications. Its high weldability makes the powder ideal for parts in larger systems because of its ability to be welded to other components.

Jerome Stanley, Höganäs Director of Global Sales, Customization Technologies, stated, "It's inspiring to see what engineers have been able to build using metal powders from Höganäs and Velo3D's support-free Additive Manufacturing process. The first parts printed using our Amperprint 0233 Haynes 282 powder are impressive, and I believe customers are only scratching the surface of what is possible with this superalloy. The powder, combined with Velo3D's end-to-end metal AM solution, is an extremely effective combination for consolidating parts into monolithic structures to eliminate coefficient of thermal expansion in large, high-performance systems."

Velo3D states that it is one of the first AM technology companies to offer Amperprint 0233 Haynes 282 powder to its customers. Many of Velo3D's customers use its end-to-end solution to produce parts for use in aviation, energy, oil and gas, space, and other high-performance applications, making the powder a good fit for Velo3D's portfolio. In addition to Amperprint 0233 Haynes 282 powder, metal powders qualified to be additively manufactured with Velo3D's technology include Hastelloy X®, Inconel 718, aluminium F357, Ti 6Al-4V Grade 5, and several other materials.

www.hoganas.com
www.velo3d.com





The combustor liner (left & centre) is made using Amperprint 0233 Haynes 282 powder from Höganäs. A cut-away view of the combustor liner (right) highlights the 23,000 unique holes included to optimise air-to-fuel ratios, and internal channels used for regenerative cooling (Courtesy Velo3D)

Advertisers' index & buyer's guide

Looking for AM machines, metal powders or part manufacturing services?

Discover suppliers of these and more in our new advertisers' index and buyer's guide, pages 226-230

Nichols Portland acquires Alpha Precision Group

Nichols Portland, Inc, headquartered in Portland, Maine, USA, has acquired the assets of Alpha Precision Group, LLC (APG), St Mary's, Pennsylvania, USA. Nichols designs and manufactures Powder Metallurgy components for use in fluid transfer devices and other automotive and industrial applications. It is also a portfolio company of Altus Capital Partners II, L.P., an investment firm focused on middle-market industrial companies. The financial terms of the transaction were not disclosed.

APG is a metal-forming technology company providing conventional Powder Metallurgy, high-temperature stainless steel PM, Metal Injection Moulding and Additive Manufacturing components and assemblies, as well as high precision valve assemblies to a global customer base. The company is comprised of five manufacturing plants located in Pennsylvania and Michigan, with over 400 team members.

"The APG acquisition is an excellent complement to our existing value proposition that focuses on being a solution provider to our customers," stated Thomas Houck, president and CEO of Nichols. "The APG network will bring additional and unique capabilities to service an ever-changing marketplace. The acquisition of APG will allow us to further accelerate the depth and breadth of our capabilities and ever-evolving needs of our customers. We feel that our approach to long-term customer relations and growth is highly aligned with the value and mission of Nichols."

Heidi Goldstein, Partner at Altus, commented, "The combination of Nichols' industry experienced management team, APG's management team, skilled workforce, and technical expertise, make us very excited about the growth possibilities of these businesses."

www.alphaprecisionpm.com
www.altuscapitalpartners.com
www.nicholsportland.com

Farsoon's AM blades carry speed skaters to Olympic gold

Early last year, Farsoon Technologies, headquartered in Changsha, Hunan, China, signed an agreement with the Chinese Olympic Committee to develop next-generation ice skating blades. Farsoon responded with additively manufactured blades made of AlMgSc – developed for use in high-impact industries such as aerospace – in an effort to achieve lightweight, high-strength parts with highly customisable designs. As the 2022 Beijing Winter Olympics drew to a close, the blades from Farsoon seem to have proved themselves; the Chinese Short Track Speed Skating team came away with two gold medals in the 500 m race.

At the beginning of this project, a series of dynamic data relating to each skater were collected for analysing the stress on the blades and stanchions (the piece that attaches the blade to the shoe) during the starting, speeding, relays and turns. According to the data, Farsoon conducted a variety of topology optimisation tests on the blades in order to achieve streamlined geometry, with a significant weight reduction of over 20% compared with the traditional blade. The new designs were also said to meet the requirements for quick installation, positioning and processing of the blades.

The light-weight skate blades (Courtesy Farsoon Technologies)

To achieve the final results, the Farsoon R&D team tested various iterations, fine-tuning the processing parameters and studying the resultant mechanical properties (i.e, strength, toughness and fatigue). The company chose its large-format Laser Beam Powder Bed Fusion (PBF-LB) AM machine, the FS421M, to produce the blades. The blades were said to show increased lateral and tangential strength during complex, rapid movements when compared to traditional aluminium alloy blades.

"Farsoon's 3D printed skate blades showcases better flexibility in use due to the reduced weight, which offers smoother and better ice grip at cornering and sharp turns," stated a member of the short track speed team. "During our regular tests under many extreme conditions, the optimised blades can successfully withstand the mechanical pressure generated by both intensive starting and fast sliding."

www.farsoon.com

Fraunhofer IAPT highlights benefits of optimised AM with automotive door hinge redesign

The Fraunhofer Research Institution for Additive Production Technologies (IAPT), Hamburg, Germany, has conducted a redesign project for the arm of a door hinge for a high-profile sports car using Additive Manufacturing to highlight the benefits of the technology. The additively manufactured part reported approximately 50% lower cost and 35% weight savings compared to an equivalent milled part.

Aided by software, commercially available from 3DSpark, a Fraunhofer IAPT spin-off, the Fraunhofer engineers first identified a suitable component. They then determined the cost-optimal orientation of the component in the AM process. Using the optimised orientation, it was possible, for example, to minimise the number of support structures required while maximising the number of components that could fit on a build platform. The identified component orientation is reported to have led to cost savings of 15% compared to an AM process without such optimisation.

In the next step of the redesign, the structure of the hinge arm was optimised in a targeted manner, using one of the benefits of Additive Manufacturing in that it enables completely new component geometries explains Fraunhofer IAPT. This gave the component a basic shape that only contained material where the simulated force flow required it. In total, this reduced the weight of the door hinge arm by a reported 35% and, due to the reduced material requirements and the shorter build time, the costs compared to AM without structural optimisation dropped by another 20%.

Any support structure that does not require removal saves time and avoids part of the significant costs incurred in the highly manual post-processing phase. Reducing the number of support structures in the design also has a positive effect on production time and material requirements, which cuts costs again by 10%. Skilful selection of the optimum metal powder material from the increasingly broad portfolio of AM materials makes it possible to lower costs by another 10%.

Additionally, adjusting the AM process parameters provides further ways to reduce costs. For example, higher layer thickness during Additive Manufacturing, optimisation of process parameters, and deformation of the laser beam profile significantly reduce build time. Even though this results in a slight loss of part quality (though still superior to that of cast parts), it enables AM costs to be reduced by a further reported 15%. Optimising machine utilisation by nesting and, if necessary, stacking in the build area, leads to further cost savings of 10%.

Summarising the redesign project results, Fraunhofer IAPT reporters that designing with Additive Manufacturing in mind and following a 'design-to-cost' approach throughout allowed the hinge arm to be manufactured at 80% less cost than an additively manufactured part without the same optimisations. This overall percentage can be broken down as follows: orientation and topology optimisation, as well as support optimisation, contribute 45% and optimised material selection, speed parameters and workload maximisation in the AM process reduce costs by a further 35%.

Fraunhofer IAPT was able to show that a cost reduction of AM by a factor of five is feasible. In parallel, brought an increase in the technical performance of the vehicle through lower weight and improved optics. The most important point, however, is that this enabled the cost of manufacturing a small series of hinge arms for a sports car door to be reduced by 50% compared to conventional milling. The organisation concluded that Additive Manufacturing is therefore not only superior to milling in terms of technical performance, but also significantly more cost effective.

www.iapt.fraunhofer.de

Fraunhofer IAPT redesigned the arm of a door hinge for a sports car using AM (Courtesy Fraunhofer IAPT)

Addman Engineering expands its refractory metals expertise with the acquisition of Castheon

Addman Engineering, headquartered in Bonita Springs, Florida, USA, has acquired Castheon Inc., a provider of Additive Manufacturing technologies for mission-critical space applications, based in Thousand Oaks, California, USA.

"This investment affirms Addman's strategic proposition in space," commented Joe Calmese, Addman CEO. "We believe that the technologies created by Dr Gao will revolutionise the Additive Manufacturing industry and transform thinking around component development for the end markets that Castheon serves. Dr Gao's accomplishments represent the cutting-edge of Additive Manufacturing, especially in refractory metals applications and solutions for the space industry."

Founded by Dr Youping Gao in 2016, Castheon is a developer of AM processes that aim to expand the use of traditionally difficult to manufacture refractory metals. Castheon partners with spacecraft companies to design, develop, and additively manufacture complex components with quick turnaround times.

Dr Gao stated, "Castheon has made major breakthroughs in technology to print refractory metals, including demonstrated success in difficult applications such as reaction control system (RCS) thrusters for spacecraft customers. Castheon's technology and know-how, combined with Addman's scale and resources, will supercharge the next chapter of Castheon's growth. Addman brings a national manufacturing and engineering footprint with over 300 employees, dozens of Additive Manufacturing machines and key quality certifications, and over 100 traditional subtractive machines to Castheon's customer base."

Kevin Wilken, Partner at American Industrial Partners (AIP), the parent company of Addman, added, "The ability to efficiently produce certain refractory metals via Additive Manufacturing is a breakthrough for customers who depend on high-temperature structural components. Castheon's offerings, which include solutions to print niobium and other refractory metals, have the potential to transform the way additive serves advanced industries. AIP is fully committed to support the continued growth of the combined company. We welcome Dr Gao to the Addman team and look forward to delivering innovative solutions that enable our customers' success."

www.addmangroup.com
www.americanindustrial.com
www.castheon.com

Rotary surface grinders help to streamline build plate resurfacing

A number of metal Additive Manufacturing processes require the part to be cut from the build plate once finished. All residual metal left on the build plate between each build requires removal and the build plate needs to be completely level and correctly textured prior to additively manufacturing the next part. In series production, this can often result in a bottleneck, explains DCM Tech Inc, a producer of rotary grinders based in Winona, Minnesota, USA.

Since the metal part is 'welded' to the build plate, it is typically removed with electrical discharge machining (EDM) wire or a bandsaw. However, these approaches involve removing a thin layer of the build plate surface, gradually reducing its thickness until it is no longer usable. Most of the cuts are not entirely flat or level, either.

One alternative is to cut close to the part, but this leaves material that must be removed later. With EDM and bandsaws, the process can take hours and hard materials like Inconel tend to strain-harden, further increasing the difficulty. Some shops even address the issue with a CNC milling machine, but this can also take hours and limit the availability of the equipment for actual production.

A more efficient alternative, explains DCM, utilises advanced precision rotary surface grinders to remove unwanted residual material with a large rotary grinding wheel surface. This technology has long been used in metalworking and glass grinding to create perfectly flat, parallel surfaces. The equipment is ideally suited to the AM process and quickly and accurately removes any residual metal from the build plate surface, restoring it to precise dimensions. The most advanced units even offer automation that allows minimally experienced operators to set them up and then attend to other tasks. This comprehensive approach is helping to exponentially speed build plate resurfacing, boost AM production, and improve quality.

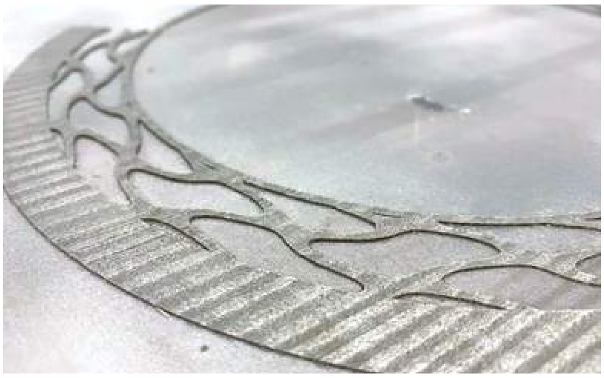
More advanced units, such as those from DCM Tech's IG series, offer variable speed grinding with automation and controls that allow virtually any operator to successfully manage a unit. These units can control the initial contact between the abrasive wheel and the build plate, which, in the past, had to be controlled by the operator. Advanced sensor technology detects vibration and can automatically fine-tune the pressure of the spindle motor and how quickly it moves the wheel down onto the build plate. When the machine senses the abrasive wheel has contacted the build plate, it automatically begins the grind cycle.

One aspect that expedites production is the operator's ability to accommodate grinding of extremely hard residual material like Inconel or titanium from build plates. This typically involves working with an expert vendor that can tailor the surface grinder's abrasives to accommodate different types of metals and alloys, as well as the materials used for the build plate.

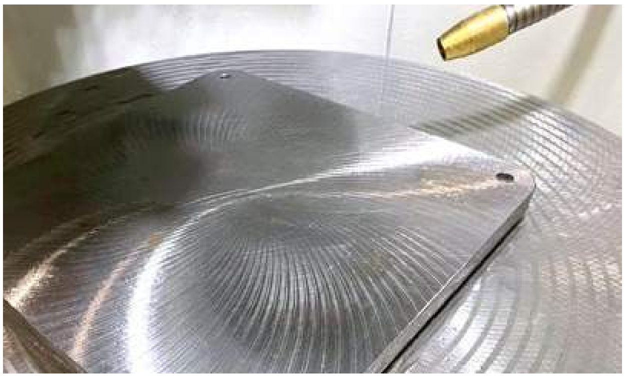
Advanced rotary surface grinders remove unwanted material on the build plate (Courtesy DCM Tech Inc)

Also important is the ability to alter the parameters through the grind cycle to handle both the additively manufactured metal/alloy and the material used for the build plate. The material characteristics of the build residue and the build plate are very different, so the rotary grinder must appropriately adjust to each on contact. Once the grinder cuts through the residual part material and reaches the actual plate, the grinding abrasive must work completely differently. The rotary grinders automatically make that transition.

www.dcm-tech.com



All residual metal left on the build plate between each build requires removal (Courtesy DCM Tech Inc)



Rotary grinders efficiently remove a range of metal remnants such as aluminium, titanium, and Inconel from the build plates (Courtesy DCM Tech Inc)

KAM continues growth with cybersecurity and QA

Keselowski Advanced Manufacturing (KAM), Statesville, North Carolina, USA, reports that it has continued its growth in hybrid manufacturing with the implementation of its digital ProShop Enterprise Resource Planning (ERP) for streamlined quality control, as well as end-to-end cybersecurity protocols.

As a reflection of the company's interest in data protection, KAM has also implemented the Corvid Cyberdefense Haven Security Solution which supports network, email, and end-point security with a dedicated Security Operations Center. This military-grade system is a component of KAM's NIST SP-800 171 compliance and the emerging CMMC 2.0 requirements.

"Having opened in 2018, KAM is ramping up quickly thanks to customer growth in the private space launch and prime defence industries. In order to continue expansion in 2022 and beyond, we knew we needed to work towards CMMC compliance, invest in cyber security, and roll out a digital ERP to satisfy the rigorous quality standards our customers expect," said Brad Keselowski, owner and founder of KAM. "Providing a fully integrated AM supply chain for space, aerospace, defence and other precision industries is more than standing up the manufacturing capital investment – it is the digital standards and quality compliance behind a strong machinery complement that speaks to KAM's commitment to quality."

The company also increased its physical attributes with the adoption of twelve metal Additive Manufacturing machines from EOS and two from SLM Solutions, as well as equipment for milling and post-processing.

www.kamsolutions.com

Amiga Engineering partners with Australian SME for AM space components

Over the past eighteen months, Amiga Engineering Pty Ltd, Tullamarine, Australia, has been working with Gilmour Space Technologies, Helensvale, Australia, to develop metal AM components for its launch vehicle.

Amiga was selected so the launch services company could leverage its Design for AM (DfAM) experience and make use of its suite of AM machines and in-house CNC machining shop. The company is reputed to have the largest service bureau for AM in Australia, with a full suite of metal and polymer AM machines, including Laser Beam Powder Bed Fusion (PBF-LB) machines from 3D Systems, Rock Hill, South Carolina, USA. These were chosen by Amiga due to the low ppm of oxygen content, key for denser parts and reducing the amount of post-processing involved.

www.amigaeng.com.au

SLM Solutions part of encrypted cloud-to-build AM solution

Customers can select ShipParts.com files and additively manufacture them on an SLM Solutions machine via a Viaccess-Orca's encryption platform (Courtesy ShipParts.com)

In combination with SLM Solutions, Lübeck, Germany, French telecommunications company Viaccess-Orca and ShipParts.com have announced a fully automated solution to enable direct cloud-to-build Additive Manufacturing with Intellectual Property security.

The solution will allow parts data from the ShipParts.com cloud to be transferred using Viaccess-Orca's Secure Manufacturing Platform (SMP) directly to SLM's machines. Part files remain encrypted, and cannot be additively manufactured until permission is granted, thus ensuring effective production control in a distributed manufacturing paradigm and the prevention of file tampering.

"As a pioneer in the field of digital assets distribution and traceability for Industry 4.0, with over twenty years of experience in designing, developing, and operating digital content security systems, Viaccess-Orca is pleased to once again set the standard for secure Additive Manufacturing together with its partners ShipParts.com and SLM Solutions," stated Alain Nochimowski, Chief Technology Officer at Viaccess-Orca. "The native integration of our Secure Manufacturing Platform with SLM Solutions machines brings to the market a new value proposition and paves the way to truly distributed manufacturing."

Nicolas Lemaire, Software Product Manager at SLM Solutions, concluded, "The Viaccess-Orca integration with SLM Solutions machines offers our customers a secure end-to-end solution that allows distributed manufacturing models around the globe. This integration is made possible thanks to our open architecture strategy that empowers our customers to benefit from our industry-leading Additive Manufacturing systems."

www.viaccess-orca.com
www.slm-solutions.com
www.shipparts.com

Incus closes Series A investment round, adds former EOS CEO Adrian Keppler to team

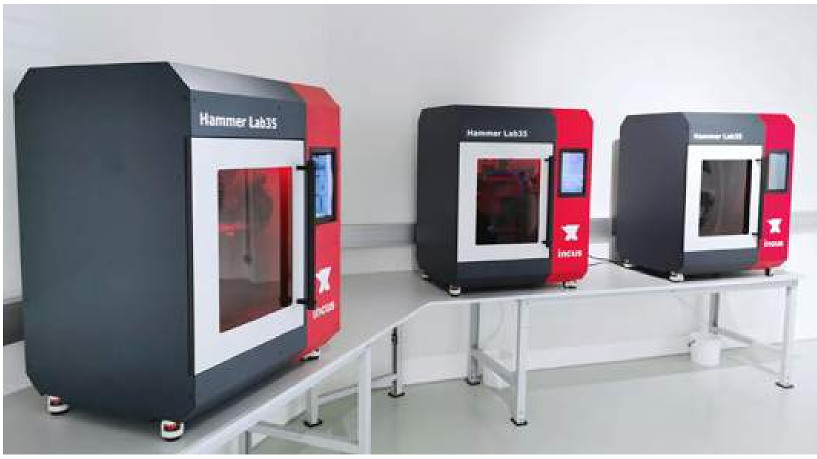
Incus GmbH, Vienna, Austria, reports that it has closed a Series A investment round in Q4 2021 which included existing investor AM Ventures. Additionally, the company is also appointing Adrian Keppler, former CEO of EOS GmbH, as an investor and growth consultant.

Founded in 2019, Incus provides lithography-based metal manufacturing (LMM) technology, defined as a Vat Photopolymerisation process (VPP) by ISO/ASTM. With this Series A investment, Incus aims to accelerate the development of its LMM technology and further industrialise its current AM solution.

In the last two years, Incus has grown its team from four to sixteen employees and Keppler has been brought on board to offer guidance on further growth. It is hoped that Keppler will help to transform Incus from a product to a solution business focusing on overall customer success.

"Any new industrial AM solution has to prove additional value," commented Keppler. "The Incus LMM technology is competing with Metal Injection Moulding, Powder Metallurgy as well as Investment casting processes. We are working with world-leading companies active in the Incus core industries to transform applications from traditional to Additive Manufacturing."

Additively manufactured parts produced with Incus' LMM technology (Courtesy Incus GmbH)



Incus aims to accelerate the development of its lithography-based metal manufacturing technology (Courtesy Incus GmbH)

He continued, "These success stories are key for the further adoption of the LMM technology and development from niche to mainstream. I'm excited to join the Incus team, help them bring their technology to the forefront of the industry and to profitably grow the business."

The company intends to team up with industry leaders to get feedback on their expectations in industrialised AM part production with a new AM machine concept including a larger building volume and simplification of post-processing steps. This evolution in combination with automation is anticipated to lower the cost per part and allow the manufacturing of larger parts at the same build speed.

"The continued support of our investors underscores the potential of our technology and enables us to expand our operational and R&D capability," stated Dr Gerald Mitteramskogler, CEO of Incus. "Our production-scale printer is symbolic of our future goals. In sinter-based AM, post processing and the manual work it entails is time-consuming and we are planning to provide new solutions to simplify these steps, especially for smaller parts."

Incus explains that the post-processing of smaller, complex additively manufactured green parts, specifically the cleaning step, can account for more than 50% of the total manufacturing costs due to manual labour. As a part of the company's LMM technology, it is developing new ways of simplifying these steps to minimise labour via automation and reduce costs.

Johann Oberhofer, Managing Partner at AM Ventures, added, "Post-processing is one of the biggest pain points in Additive Manufacturing. We believe that with Incus and the LMM technology we have a manufacturing solution in our portfolio that can bring the industry closer to a practical solution for mass manufacturing."

www.incus3d.com
www.amventures.com

The new model
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We have added a number of improvements over the standard Fast Wire Edms including:

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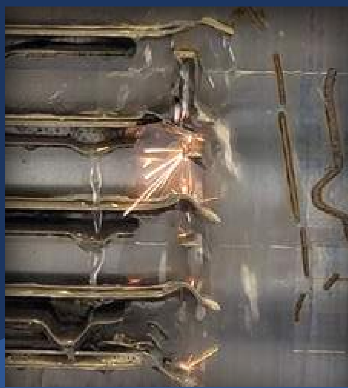

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Purdue University adds Hypersonics Advanced Manufacturing Technology Center

Purdue University, West Lafayette, Indiana, USA, reports that it will expand its hub of hypersonics research by establishing the new Hypersonics Advanced Manufacturing Technology Center (HAMTC). The centre will be focused on developing high-temperature materials and creating new manufacturing processes to build and join these materials, which aims to extend hypersonic vehicles' capabilities. GE Additive will be the primary partner for Additive Manufacturing at HAMTC, providing AM machines that are customised to processes developed at the facility.

The HAMTC will be a single location at the university to allow industry partners, including GE Additive, Dynetics, Lockheed Martin, Aerojet Rocketdyne, GE Edison Works, Boeing and several small businesses, to work on materials and manufacturing innovations and provide access to testing capabilities at Purdue that are hoped to enable the US to overtake competitors in the field.

The centre will be located in the planned approximately 6000 m^2 Hypersonics and Applied Research Facility (HARF), which was established in 2021. In addition to HAMTC, the $41 million HARF facility will house a Mach 8 quiet wind tunnel and the hypersonic pulse (HYPULSE) reflected shock/expansion tunnel.

Air resistance at hypersonic speeds (more than five times the speed of sound) creates extremely hot temperatures, causing surface-level reactions that break down materials.

"When you heat up 3,000°F [1,648°C], small differences in expansion can cause large stresses between components made of different materials that may result in failure of hypersonic vehicles," stated Michael Sangid, executive director of HAMTC and the Elmer F Bruhn Professor of Aeronautics and Astronautics. "At HAMTC, we can essentially increase the temperature capabilities of materials via new compositions, create new manufacturing routes to produce complex geometrical designs, and join these dissimilar materials together, in order to meet the requirements of hypersonic environments."

A graduate student prepares to measure the thermo-mechanical strength of prototype materials for hypersonic vehicles in the Advanced Computational Materials and Experimental Evaluation Lab (Courtesy Purdue University/Vince Walter)

HAMTC is the first contract through the Purdue Applied Research Institute (PARI), the university's new nonprofit applied research arm. OSD Manufacturing Science & Technology Program (MSTP) is partnering with NSWC Crane and National Security Technology Accelerator (NSTXL)'s Strategic & Spectrum Missions Advanced Resilient Trusted Systems (S2MARTS) to address these critical capabilities through advanced manufacturing of hypersonic technologies. PARI received a thirty-month, $18.6 million contract to directly address the hypersonic weapons development gaps.

"The potential and opportunity for Additive Manufacturing in hypersonics is huge," added Chris Schuppe, general manager – engineering and technology, GE Additive. "We are honoured to be part of Purdue's team supporting the Department of Defense in manufacturing research that will advance US national security and competitiveness; we value results-driven, industry-academic collaboration in industrialising additive. Our team – many of whom are Purdue alums – are excited to get started."

Material development and manufacturing at HAMTC offers applications for consumer products and a number of industry applications, including aerospace transportation, green energy, and nuclear applications. The hypersonic aspect also relates to space exploration, particularly vehicles travelling at hypersonic speeds as they re-enter the Earth's atmosphere.

"What is unique about this is our ability to work hand-in-hand with industry," Sangid concluded. "We'll have researchers and students work on real industrial and defence problems, while at the same time advances and transitioning innovations in high temperature materials and cutting-edge Additive Manufacturing."

www.ge.com/additive
www.purdue.edu

Optisys partners with NRAO to explore AM antennae for radio astronomy

Optisys, LLC, headquartered in Salt Lake, Utah, USA, has partnered with the National Radio Astronomy Observatory (NRAO) based in Charlottesville, Virginia, to explore the potential of additively manufactured orthomode transducers (OMTs) and other electromagnetic devices for radio astronomy applications.

In radio astronomy, the performance of antennae, waveguides, and other electromagnetic parts help determine the capability and sensitivity of radio telescopes and the quality of scientific data they deliver to researchers. The more capable and sensitive the antenna and other devices, the more scientists can learn about the universe. NRAO's Central Development Laboratory (CDL) is continuously testing new technologies in pursuit of building better telescopes.

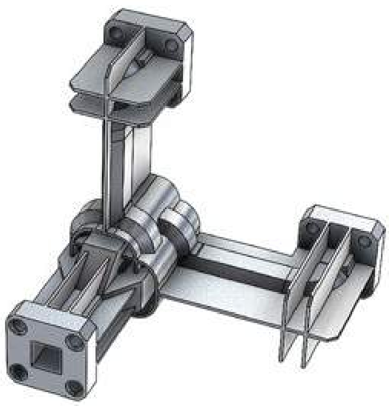


Illustration of the external view of a potential AM orthomode transducer with a flange connector (Courtesy Optisys/NRAO)

Optisys explains that its design capability allows for the smallest SWaP RF products, which further decreases the losses, and increases the stability, of the antennae used in such apparatus. These are favourable attributes in radio astronomy, especially when the antenna is required to be operated at cryogenic temperatures. The nature of Optisys technology, being so highly integrated, and not requiring plating to provide excellent performance, means it is an excellent candidate to be the basis of the next generation of increased-range and higher-accuracy, land and space-based radio telescopes.

"Understanding the universe requires us to push the limits of science, technology, and knowledge," stated Tony Beasley, Director of NRAO. "CDL has been at the forefront of this effort in radio astronomy for decades and, with the help of Optisys, will continue to lead the industry in innovative solutions."

Optisys and NRAO are both said to be excited about the potential of where Optisys' design capability will assist in shedding light on our universe's birth and inner workings. Traditionally designed and manufactured RF solutions are reported to have a restriction in their capability that limits the scope of information that can be detected by a single telescope. Optisys' advanced antenna capability is expected to expand that scope, leading to a richer and more defined dataset.

The company is expected to commence production soon on the first test device, an orthomode transducer (OMT), with delivery expected by the end of 2022. OMTs separate the two polarisations found in many radio astronomy signals and help astronomers analyse collected data. The new additively manufactured OMT will be compared against those produced through traditional machining techniques and used as a baseline for designing and improving future devices.

www.optisys.com
public.nrao.edu

PST's SIL-rated oxygen analyser for Additive Manufacturing

Process Sensing Technologies (PST), Ely, Cambridgeshire, UK, offers an oxygen analyser for inertisation applications in Additive Manufacturing, the Ntron SIL102 Oxygen Analyzer. The low-cost analyser can be configured for SIL 1 or SIL 2 applications with the addition of a second sensor; this complete system (analyser and sensor) meets the requirements of IEC 616598 SIL2.

Materials used in metal Additive Manufacturing (e.g., aluminium, titanium and their alloys) are combustible even in their smallest particulate form. As the AM process itself generates dust, a fire or explosion can result in an oxygen environment when these particles come into contact with an ignition source. With a measurement range of 0-25% O2, Ntron SIL102 Oxygen Analyzer aims to negate this risk with safety-critical process control applications.

The machine features three configurable alarm settings via a four-button user interface and is suitable for harsh process applications. All resultant analysis is displayed clearly via an LCD screen.

The Ntron SIL102 Oxygen Analyzer has been designed to specifically address AM safety requirements (Courtesy PST)

www.processsensing.com

Rosswag supplies AM parts for high-power telescopes

Rosswag Engineering, Pfinztal, Germany, a supplier of metal powders, metal additively manufactured components and qualification services, has produced structural AM parts for six metre mirrors in two telescopes from CPI Vertex Antennentechnik GmbH: the Fred Young Submillimeter Telescope (FYST) and the Simons Observatory Large Aperture Telescope (SOLAT).

The mirrors in these telescopes must maintain a high dimensional accuracy to function correctly, even when under temperature variations. To achieve this, Rosswag selected Invar 36®, an iron-nickel alloy noted for its low thermal expansion and well suited for demanding measuring instruments such as these sensitive and high-precision telescope systems.

"Because we have a high number of variants and a low number of pieces per variant for these Invar 36 components, the [PBF-LB] process is economical and competitive compared to, for example, welding or machining," stated Michael Solbach, Mechanical Design at CPI Vertex Antennentechnik. "In addition, geometries can also be created that would not be possible with other manufacturing processes, or only at great expense."

Rosswag has additively manufactured mirrors for two millimetre and sub-millimetre telescopes (Courtesy Rosswag)

The Fred Young Submillimeter Telescope studies the dynamic interstellar medium in the Milky Way, the Magellanic Clouds and other nearby galaxies. Among other things, it collects measurements to place new constraints on dark energy and the sum of the neutrino masses.

The Simons Observatory Large Aperture Telescope is a crossed Dragone optical design with a six metre diameter aperture to explore CMB science at small angular scale.

www.rosswag-engineering.de

BCN3D introduces autocalibration for its AM machines

BCN3D, Barcelona, Spain, has introduced a new method of autocalibration for its Additive Manufacturing machines. The new electronics system controls a piezoelectric sensor, mounted on the buildhead between the hotend and x-axis, which detects pressure to accurately measure the exact distance between the nozzle tip and the build surface.

According to the company, one of the best usages for this sensor is mesh mapping (measuring the flatness of the build surface). To carry this out, the toolhead moves along nine points, distributed across the build plate, in order to configure the most accurate Z alignment.

Autocalibration also carries out another process in an effort to ensure the perfect XY alignment for BCN3D's dual extrusion system; at the back of the build plate, a square perimeter is used to calculate the perfect offsets between the two toolheads, eradicating any risk of crossover in a dual build.

These automatic processes collectively mean build set-up time may be reduced from forty to six minutes – a reduction of 85%. By removing human criteria, the possibility of errors and build failures are said to be reduced and BCN3D guarantees a correct first layer adhesion with each use.

www.bcn3d.com

PrinterPrezz and Uniformity Labs aim to reduce cost of AM medical devices

PrinterPrezz, Inc, and Uniformity Labs, both of Fremont, California, USA, have signed a Memorandum of Understanding (MOU) to utilise Uniformity's Laser Beam Powder Bed Fusion (PBF-LB) and Binder Jetting (BJT) for medical device applications.

The first joint effort will be the qualification of Uniformity Labs ultra-low porosity Ti64 titanium powder at PrinterPrezz's innovation centre to produce implantable medical devices, beginning with the spine implants manufactured on 3D Systems' ProX DMP AM machines. Utilising this powder is expected to reduce build time and lower the cost to manufacture end parts. Together, the companies will seek to qualify spine implants through the FDA regulatory approval process.

"We aim to leverage the qualification of Uniformity Lab's metal powders to accelerate new product introduction and reduce device costs for patients around the globe," stated Shri Shetty, CEO, PrinterPrezz. "Uniformity's powders have a history of exhibiting superior mechanical properties and higher machine productivity, which will help us continue to push the boundaries of innovation in the medical device industry. Our executive teams have collaborated closely over the last few years and recognised the considerable synergy. We are excited to leverage this partnership to reduce device costs and expand the reach of our medical platform."

Adam Hopkins, CEO of Uniformity, added, "This is a tremendous market opportunity and the perfect application for our ultra-low porosity titanium powder. We have an excellent working relationship with PrinterPrezz and are excited by the prospect of combining our novel technology with their life-changing innovation platform. Other industries have already adopted our printing processes to significantly enhance the 3D printing value proposition and we look forward to having the same impact in the medical segment through this partnership."

PrinterPrezz will manufacture medical devices with Uniformity Labs' ultra-low porosity powders (Courtesy Uniformity Labs)

Uniformity founding advisor and VP of Business Development, Geoffrey Doyle, serves as an advisor to the PrinterPrezz executive team and board of directors.

www.uniformitylabs.com
www.printerprezz.com

Cornell software supports AM on International Space Station

Modelling software from Cornell University, Ithaca, New York, USA, has been successfully tested on board the international space station (ISS) as part of a collaboration between the university, Hewlett Packard Enterprise (HPE), NASA and the ISS US National Laboratory. The software, created by the Cornell Fracture Group, simulates the Additive Manufacturing process and allows the user to build more successful parts.

The experiment, conducted on January 1, was part of an ongoing effort to demonstrate the functionality of the HPE Spaceborne Computer-2, an edge computing system with artificial intelligence capabilities which is expected to enable real-time processing of large amounts of data in space, without the data being relayed between Earth.

For the last year, astronauts have been running an array of experiments on the system, ranging from processing medical imaging to DNA sequencing to Additive Manufacturing. While on earth AM can benefit from simulation models, it becomes all the more important in space. The lack of gravity, differences in time and spatial scales, and radical changes in temperature could all hinder the process, resulting in wasted material and unusable parts.

"Let's say you're in space and you need a part," stated Derek Warner, professor at the College of Engineering who heads the Cornell Fracture Group. "If you just were to draw the part or upload a CAD file to your 3D printer and press print, it probably won't work, just because 3D printing isn't at that level of maturity. You would need to adjust the printing process and the parameters, so it will come out successful and you won't waste your material."

Utilising experience gained in the Cornell Fracture Group, where research is conducted to better understand the deformation of AM structures, doctoral student Terrence Moran designed the modelling software to act as a virtual Additive Manufacturing machine, in an effort to save time and material.

"Previously, this was computationally infeasible due to discrepancies in time and spatial scales and high thermal gradients," Moran stated. "So we developed the software with a physics-based model, made it portable, and uploaded it to the ISS. It was successfully run and the results were consistent with the results we'd done during our research. The timing and everything were the same."

On the potential applications of this software, Warner concluded, "One of the allures of 3D printing is that you can manufacture locally. So the neat thing about this is that, while space might be the most extreme environment, for the military or on oil rigs or other places, there's also going to be a need for doing the same thing. This demonstrates that it's possible."

www.cornell.edu

TUM and Oerlikon form Advanced Manufacturing institute

The Technical University of Munich (TUM) and Oerlikon, Pfäffikon, Switzerland, have jointly founded the TUM-Oerlikon Advanced Manufacturing Institute to advance Additive Manufacturing technologies and contribute to the goal of industrialisation. The institute is based on the TUM campus in Garching, Germany, and will be funded with an annual budget of €3 million during the first five years.

"Together with Oerlikon, we wish to transform Munich to become recognised globally as a centre of Additive Manufacturing technologies," stated Professor Thomas F Hofmann, TUM president. "This collaboration perfectly complements our Industry on Campus strategy of bringing science and practical applications closer together and making substantive contributions to the industrialisation of Additive Manufacturing technologies."

The researchers at TUM and the scientific team from Oerlikon's AM business unit will work together at the institute over the next five years to supervise up to thirty dissertations focusing on technical research along the entire value chain These include the development of new, tailor-made materials, studies on the building process and the reciprocal interactions between processes and materials, as well as the entire AM process.

Dr Sven Hicken, CTO, Oerlikon Surface Solutions Division, commented, "To further the collaborative synergies between the university and ourselves, we have decided to relocate our business activities together with our in-house research department from Feldkirchen to Garching. Both partners benefit from such a partnership: doctoral students can use our hardware, including our 3D printers and our laboratories, and we are close to the research activities of a truly excellent university."

Dr Nikolaus A Adams, Director of the Chair Aerodynamics and Fluid Mechanics at TUM, who is responsible for the institute, explained, "Our research efforts focus primarily on technical challenges which, once we have surmounted them, will speed up the development of 3D metal printing. For example, we are already working together on the new ultra-strong, light aluminium-based alloys that are in high demand in the industry, on demanding new simulation techniques to predict the melting and solidification process for metal powders and on the development of a digital certification process using components produced for the aerospace industry with the help of advanced manufacturing."

www.oerlikon.com

Sigma Labs brings PrintRite3D to Aconity3D's AM machines

Sigma Labs, Inc, Santa Fe, New Mexico, USA, has announced that its PrintRite3D® in-process QC solution will be certified to work with the line of metal Additive Manufacturing machines from Aconity3D, Herzogenrath, Germany. As an original equipment manufacturer, Aconity3D will sell, install and support PrintRite3D as an integrated solution to its customers.

"I am very pleased to announce our partnership with Aconity3D. Aconity3D's customised and modular Additive Manufacturing systems are an ideal use case for PrintRite3D," stated Mark Ruport, president and CEO of Sigma Labs. "We believe their unique approach to building systems in a wide variety of possible machine configurations to meet end users' specific needs combined with our in-process quality assurance solution will help enable industrial manufacturing at large scale and compatible costs. We believe our collaboration will accelerate the adoption of 3D metal printing and facilitate companies moving into production more quickly and efficiently."

Dr Yves Hagedorn, CEO of Aconity3D added, "We are delighted about this partnership. We believe Sigma Lab's and Aconity3D's joint endeavour to achieve steadily increasing part quality will be a main enabling factor for further industrial applications of 3D metal printing, as well as the ability to create fascinating applications."

www.aconity3d.com | sigmalabsinc.com

Protolabs receives JOSCAR recognition

Protolabs, with global headquarters in Maple Plain, Minnesota, USA, and manufacturing facilities and offices in Europe, USA and Japan, has secured Joint Supply Chain Accreditation Register (JOSCAR) supplier accreditation for the aerospace, security, space and defence sectors. The accreditation is valued by many of the largest purchasers in these industries, such as BAE Systems, NATS, Rolls Royce, Airbus and the MOD.

JOSCAR accreditation indicates that an organisation has successfully gone through an invitation-only process that demonstrates commitment, reliability, technical ability and capacity, as well as helping purchasers meet the growing and diverse nature of regulatory requirements when it comes to managing third party risk in the supply chain.

"We are delighted to have achieved JOSCAR accreditation, joining an elite group of global suppliers in the process," stated Bjoern Klaas, vice president and Managing Director of Protolabs Europe. "It is testament to the quality and reliability of our output and our capacity to deliver prototypes and production parts in such a way that is valued by our customers in aerospace, security, space and defence industries."

He continued, "We take great pride in achieving excellence in this way, whether being at the forefront of innovation or providing a trusted digital manufacturing service to the industrial supply chain. We are already a well-established service provider to the aerospace supply chain, but this accreditation, alongside our ISO 9001 quality award, will further cement our reputation in the wider security and defence industries."

In addition to CNC and injection moulding, Protolabs has extensive metal Additive Manufacturing capabilities (Courtesy Protolabs)

"In addition, we recently became one of the first manufacturers in the EMEA region to achieve DNV certification, bringing new levels of assurance relevant to maritime and offshore industries, as well as the broader defence sector and JOSCAR-associated industries," Klaas concluded.

www.protolabs.co.uk

SLM Solutions integrates Assembrix VMS software for remote operation

SLM Solutions, Lübeck, Germany, and software developer Assembrix, Tel Aviv, Israel, have integrated the Assembrix VMS™ software with SLM Solutions' Additive Manufacturing machines. The Assembrix VMS platform enables remote Additive Manufacturing, while maintaining the high-security standards that enable OEMs to work remotely and still have complete ownership of the fully automated AM process.

A real-time data feed keeps customers updated on the building status, while advanced encryption technology ensures IP protection.

"We are excited to partner with SLM Solutions and offer our clients an end-to-end solution for secured distributed Additive Manufacturing that works seamlessly with SLM Solutions' 3D printers," stated Lior Polak, CEO of Assembrix. "The need to remotely control the Additive Manufacturing process with both existing and new suppliers is rapidly growing by manufacturers from multiple industries and locations. With Assembrix's powerful platform, SLM Solutions can create groundbreaking business opportunities for customers and other key players in the Additive Manufacturing industry."

Sam O'Leary, CEO of SLM Solutions, added, "The Assembrix integration allows our customers to take advantage of a completely secure remote printing process while further driving the optimisation of their global supply chains. It fits perfectly to our open architecture strategy, enabling and empowering our customers to do more, achieve more, and be more successful."

www.slm-solutions.com
www.assembrix.com

SLM Solutions receives order for two NXG XII 600 AM machines from leading rocket company

SLM Solutions, Lübeck, Germany, has received an order for two NXG XII 600 metal Additive Manufacturing machines from a leading aerospace rocket company based in California, USA. The new AM machines will make its space missions more affordable and efficient, by creating lighter, faster and more robust aerospace components.

With the rise in demand to get space-based technology into orbit, Additive Manufacturing is an ideal solution for space companies. SLM Solutions explains that the NXG XII 600, which uses the Laser Beam Powder Bed Fusion (PBF-LB) process, offers a large build envelope and the ability to work with space-friendly alloys such as nickel and copper. It has high-speed production rates, capable of producing complex parts crucial for the space sector's demands.

"The NXG XII 600 is a true game-changer for the rapidly growing (New) Space industry," stated Dr Simon Merkt-Schippers, EVP Product Management of SLM Solutions. "Here, traditional space companies and established players must cope with strong growth and an urgent need for complex parts to win the modern space race. SLM Solutions technology enables more affordable missions due to smarter designs that make rocket engines more efficient, bringing their performance to the next level. There is probably no faster and more efficient way to explore orbit and come out triumphant than utilising the capabilities of the NXG XII 600."

www.slm-solutions.com

SINTEF project aims to advance AM adoption in maritime sector

Over the last three years, Norwegian Research and Development partner SINTEF has been involved in FlexiMan, a collaborative European research project focused on the potential of Additive Manufacturing to make the maritime industry more efficient and sustainable. The project partners are Nordic Additive Manufacturing AS, Kongsberg Maritime AS, Fraunhofer IPK, LaserCladding Germany GmbH and Mecklenburger Metallguss GmbH.

The notion of a circular economy characterises the thinking behind the project; the goal is that the material of damaged components, or parts of the damaged components, should be reusable. As well as being sustainable, by additively manufacturing these parts at the point of need, it also minimises required storage space and removes the cost inherent in shipping over long distances.

"If we succeed, this will give suppliers to the shipping industry a great advantage in an industry with fierce competition and high demands on profitability," stated Afef Saai, project leader on FlexiMan. "In addition, we use only the materials that are needed. Nothing goes to waste."

In one example, the team was in charge of an impeller whose blades were worn. Normally, this would result in the entire impeller being discarded. As part of the FlexiMan, the team instead additively manufactured new alloy blades onto the impeller so that its functionality can be maintained for longer. And when a component is so broken that this sort of repair isn't viable, the part can be broken down into raw material so that it can be used to manufacture entirely new parts.

Compared to traditional machining, AM allows for more customised component solutions. A type of hybrid material solution is one such option: When a part is very large and has areas not as susceptible to wear, the cheaper option of using ordinary steel is possible; the smaller parts which see the most exposure be additively manufactured in more expensive, high-quality materials.

Another advantage is that you can limit the use of materials on large and heavy parts. An example is the propeller, here the scientists have a plan to develop a hollow variant. This means that less of the material can be used, that the propeller becomes lighter and thus requires less fuel. But at the same time, scientists need to know that it is strong enough.

While other large-scale industries such as aerospace and automotive have already seen the adoption of AM, the stringent maritime guidelines have been a barrier to ready adoption in that sector. SINTEF is currently testing manufacturing procedures that fit into these guidelines.

www.sintef.no

Innovation by Matsuura

Hybrid Additive Manufacturing

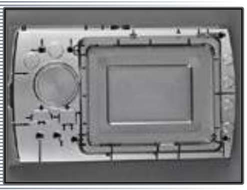
Seamless Metal Laser Sintering & Milling Process

LUMEX Avance-25

Build Volume:

(D)250mm x (W)250mm x (H)185m
(D)250mm x (W)250mm x (H)300m *

(* Option)



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The ***Matsuura LUMEX Avance-25*** is the world's first hybrid powder bed fusion machine. The combination of additive technology and ***Matsuura's*** 80 years of subtractive high speed milling technology into one seamless process, enables the production of complex, high accuracy molds and parts in a method that has never been possible, nor imagined. Further adding to ***Matsuura's*** expertise in the Hybrid metal AM field, this technology is now available on the new ***Matsuura LUMEX Avance-60*** possessing the largest powder bed platform available on the market.

LUMEX Avance-60

Build Volume:

(D)600mm x (W)600mm x (H)500m

The Matsuura Avance-60 the largest hybrid powder bed platform on the market.

More information at www.lumex-matsuura.com

Matsuura

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Nordic Additive Manufacturing reports success using DED AM technology

After using Trumpf's Laser Metal Deposition (LMD) Additive Manufacturing technology, a Directed Energy Deposition (DED) process, for five years, Nordic Additive Manufacturing (NAM), Raufoss, Norway, recently spoke to Norwegian manufacturing magazine *Maskinregisteret* about the positive results it has seen using the technology. The company began using the process in 2017, after purchasing its Trumpf TruLaser Cell 3000, and uses the technology for applications including the construction of new parts, repairs, modifications and additions to existing parts.

"It is not only toolmakers and the car industry that are our customers; everyone who makes something in metal are potential customers," stated Magne Manskow Vik, part of the NAM team. "There is a lot of talk that we can create completely new products with, for example, internal cooling ducts, and yes, we make it – in fact, we make quite extreme things, but don't forget that we can also repair and improve things that would otherwise have to be replaced with a new component."

Based on the results it has seen, the company stated that it believes laser-based DED should see further adoption across industry, beyond its currently quite niche applications.

"When today's designers gain full insight into the technology, we will have already made great gains in innovation of completely new products we have never seen before," added Sture H Sørli, General Manager at NAM. "You can only speculate about what is possible and what it will provide, but the fact that we can manufacture components with completely new properties will provide great benefits in terms of how small things can be made, improved processes and previously impossible product design."

One challenge the company has faced in its implementation of DED is strict Norwegian standards, particularly within the oil industry; this has proven difficult to counter, because DED is not described in the NORSOK standard, a collection of industrial standards developed by the Norwegian petroleum industry to ensure adequate safety, value-adding and cost effectiveness for petroleum industry developments and operations.

NAM uses AM for applications including the construction of new parts, repairs, modifications and additions to existing parts (Courtesy Maskinregisteret)

"We are working to get ISO certified, but that is not the only obstacle," continued Sørli. "The LMD [laser-based DED] process is not described in the NORSOK standard. Our solution is that we deliver both undocumented jobs to the industry that does not require it, and then we piece-certify each component we deliver to customers who require this. We test a lot, the customer often does too. Our close collaboration with Sintef gives good results. In addition, Manulab at NTNU Gjøvik performs CT scans, so we usually reach the goal with the documentation."

NAM reported that it has benefited from its partnership with some of the industrial heavyweights among its owners. In addition to its primary owner, the investment fund Komm-In, companies such as Nammo, Sintef Manufacturing, Norse Industries AS and Sparebank 1 are co-owners, as well as Tor Henning Molstad through the companies Molstad Model & Form AS and Molstad Eiendom AS. Molstad is also active as chairman of the board.

"We envisage bringing in players who make it possible with larger investments," Sørli added. "It has taken time to build competence, we have gained it, and now we are starting to make money. Then it is natural to increase capacity and build the company further with new technology and more people. We invite all interested parties to challenge us so we can show what we can produce and at the same time we would like to enter into a dialogue with interested partners."

NAM is currently participating in several research projects in the EU, with partners including Fraunhofer, Kongsberg Maritime and other German and Italian entities. "With additive production, you can achieve a fast path from idea to finished product; we have an example of a component we made for the customer that resulted in the customer being able to reduce the cycle time from two hours down to four minutes," he concluded.

www.maskinregisteret.no
www.nordicadditive.no
www.trumpf.com

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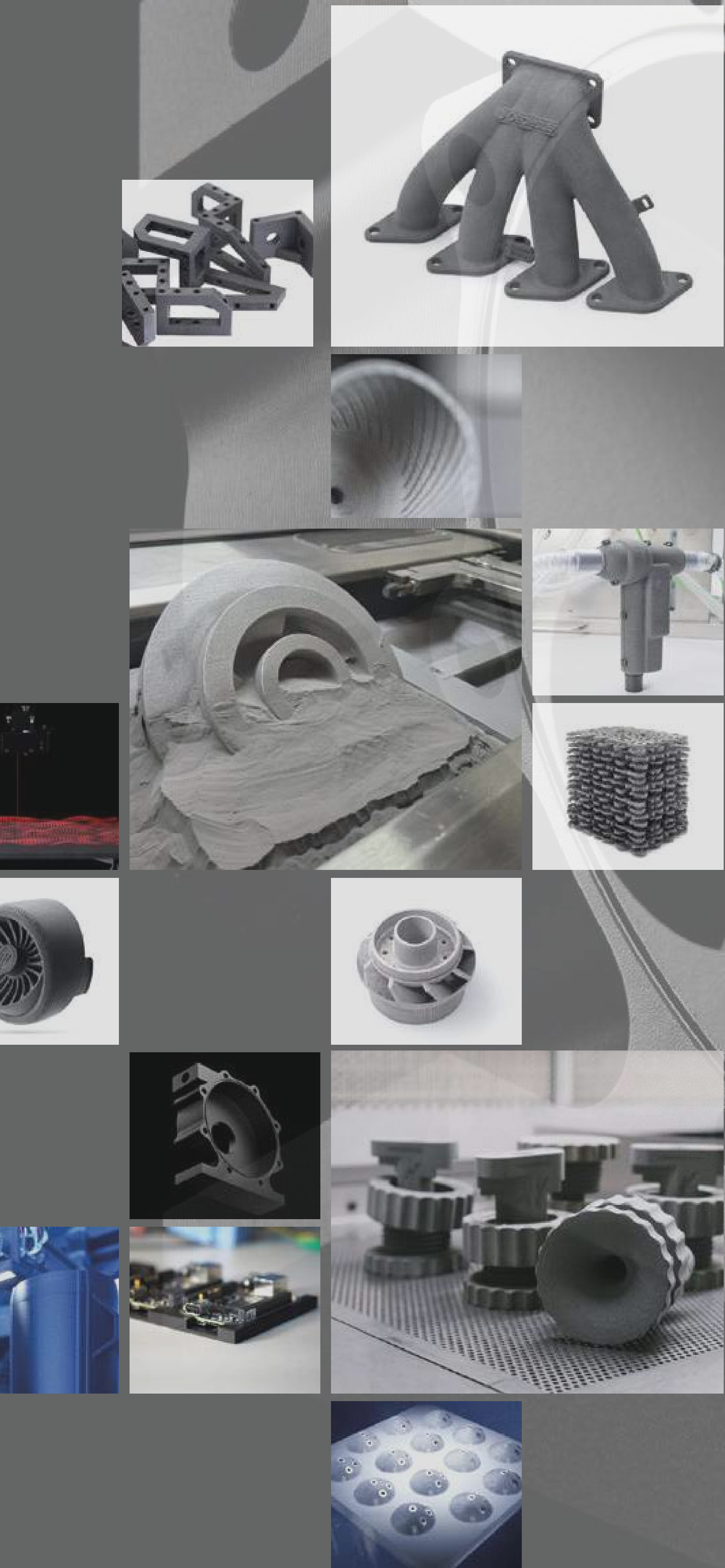

ADDTEC3DM

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- Reverse engineering
- Scan to Solid Body
- Designing for the printing process

ADDTEC3DM™ is your choice for 3D printing and fabrication services. Our 3D Accelerate program can help you build, grow, and imagine new products for your business. From idea to production, we give you a roadmap to success. Continued growth is at your fingertips with 3D Accelerate.

Discover the difference 3D Accelerate can make for your business. Rely on our manufacturing service team to make your product a reality or improve an existing part or product in your process.

ADD N' GO – 3D Printing your parts

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- Metal Binder Jet Printing
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Large Selection of Engineering-Certified Materials

For all your Metal laser, Metal binder jet, Multi- Jet Fusion, Composite, and Resin 3D printing needs, ADDTEC3DM™ can help you with our ADD N' GO 3D Printing services. Choose from a variety of options for your 3D part and component printing needs. We offer quick delivery and efficient turnaround times for all printing projects, using only the highest quality parts.

Metal materials include: 17-4, 316L, copper, Inconel 625, H13, A2, D2, and others as requested.

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- Heat treat
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- Proven process for volume production
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WWW.ADDTEC3DM.COM

DESIGN. MADE. SIMPLE

Project uses Artificial Intelligence to control DED in repair of wear parts

A German-Canadian consortium has been established to improve the quality of wear parts when repaired using laser-based Directed Energy Deposition (DED) Additive Manufacturing processes. Under the project, Artificial Intelligence Enhancement of Process Sensing for Adaptive Laser Additive Manufacturing (AI-SLAM), the team is jointly developing software that can be used to run the DED processes automatically.

In Germany, the collaboration partners include Fraunhofer Institute for Laser Technology ILT, Aachen, and the software developer BCT from Dortmund. In Canada, the project is coordinated by the National Research Council of Canada NRC. A team from McGill University, Montréal, is responsible for the research side of the project, while Braintoy, Calgary, is involved in programming the machine learning algorithms. Apollo Machine and Welding Ltd in Alberta are participating in the project as an industrial service provider for DED.

Canadian machine builders are reported to receive many orders from the mining and petroleum industries for repairing wear parts. For example, rock crusher teeth used by the mining industry need to be regularly overhauled. Using the laser-based DED process, industries can apply new layers to the worn part until the original geometrical shape has been reconstructed.

For complex geometries, such as on this blade tooth, or where wear is uneven, AI-based process optimisation will enable significant gains in efficiency (Courtesy Apollo Machine and Welding Ltd)

A problem with this repair process is the part's uneven wear, which means that layers of varying thickness have to be applied. An operator must measure this after each coating step or at least after every tenth layer and readjust the process.

The project partners aim to automate this stage. For this purpose, the system automatically records geometries during the coating process, detects deviations from the specified contour and readjusts process parameters, such as the feed rate.

The optimised control parameters are calculated with the help of Artificial Intelligence. The software analyses a larger dataset and independently learns how to iteratively improve the process. The most recent milestone in the three-year project was commissioning the software functionality for both scanning components and automatic path planning at the Fraunhofer ILT facility.

The Canadian partners are continuing to develop the DED technology for repair companies such as Apollo, which uses several tons of material annually for the repair of wear parts – such as the rock crusher tooth. Accordingly, the expectations for efficiency gains through automated process control are high.

The AI-SLAM project will run until March 2024 as part of the 3+2 funding programme with Canada. The programme is funded on the German side by the Federal Ministry of Education and Research and on the Canadian side by the NRC.

www.ilt.fraunhofer.de
www.bct-online.de
https://nrc.canada.ca
www.mcgill.ca
www.braintoy.ai
www.apollomachine.com


Explore what's possible with metal additive manufacturing:
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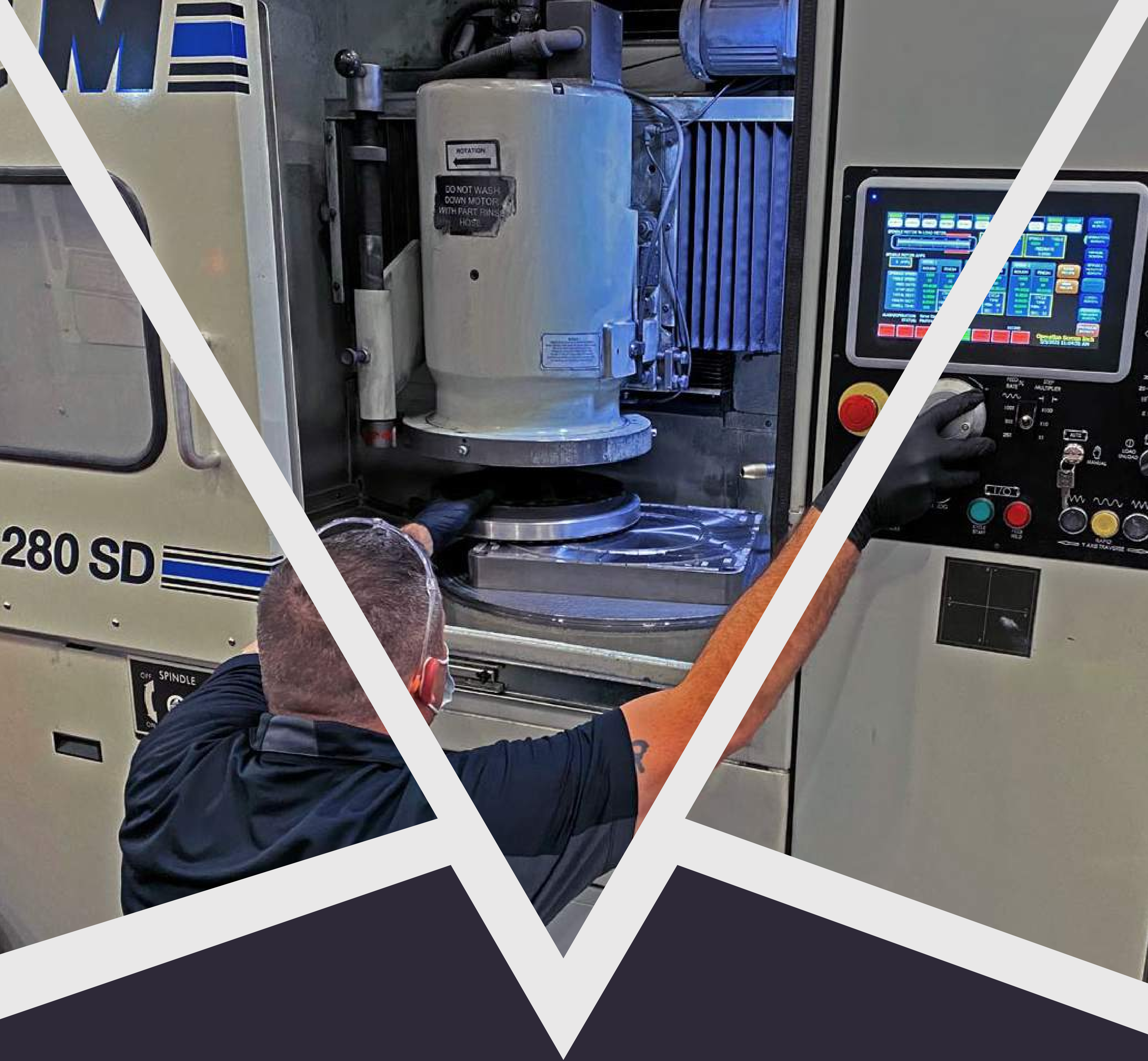
→ Mass customization
→ Consolidate assemblies
PARMATECH


ROTATION
DO NOT WASH DOWN MOTOR WITH PART RINSE HOSE
280 SD
SPINDLE

AlphaSTAR awarded Phase II DoD programme for design of new alloys

AlphaSTAR Corporation, Irvine, California, USA, has received the Department of Defense (DoD) Phase II programme award by the Defense Logistics Agency (DLA) for the design of new alloys for Additive Manufacturing entitled 'Grain Boundary Engineering for Additive Manufacturing.' The project is in collaboration with GE Research, University of Southern California (USC) Viterbi Center for Advanced Manufacturing, University of Michigan (UoM) Aerospace Engineering and Quadrus Corporation. The award intends to continue Phase I efforts in the development of technologies that can predetermine the microstructure of AM metal parts with optimal grain boundaries, resulting in predictable mechanical properties, including mode of failure for enhanced AM fabrication.

Due to the variability in the mechanical properties of metal AM parts, understanding the microstructure development & evolution during the AM process of metallic alloys is an important precondition for the optimisation of parameters to achieve desired mechanical properties.

Dr Rashid Miraj, Director of Technical Operations at AlphaSTAR, explained, "Metallic alloys consist of individual crystallites commonly referred to as grains. Individual grain connections (grain boundaries) are formed through recrystallisation during metal part fabrication and heat treatment. A grain boundary is the interface between two grains, or crystallites. Grain boundaries influence the mechanical properties of the metal; hence, certain grain boundaries are preferred over others.

"Grain boundary engineering (GBE) in Additive Manufacturing refers to methodologies and technologies associated with the build process or post-build heat treatments that drive and generate preferred microstructure outcomes associated with an AM fabricated part," he continued. "At its simplest, AM GBE may be achieved through variation of the build process that address both heating and cooling and triggers nanoprecipitation and material transformation. This technology will result in significant advancements related to the design of new parts and the repair of old parts associated with DoD supply chain. GBE for AM has the potential to increase the flexibility, scalability, and capability of AM produced parts."

The ultimate objective is to establish material performance screening, selection and improvement of AM driven legacy parts. Furthermore, it will continue to improve the developed ICME software which reduces trial and error in the AM process.

www.alphastarcorp.com

Foerster offers new induction thermography part testing

Foerster Group, headquartered in Reutlingen, Germany, has introduced a new, non-destructive automatable solution for testing sintered components using induction thermography. The technique allows for contact-free crack detection on metal components and is particularly suited to parts with complicated shapes where test areas can be difficult or impossible to access with eddy current probes.

The process is reported to identify open cracks, pores, heat treatment cracks, forging laps, welding defects, etc. It can be used on rough, uneven surfaces and surfaces coated with water or oil, with testing done in less than one second. The induction thermography method is suitable for the examination of semi-finished products as well as complexly shaped components. A current induced into the workpiece generates localised hotspots at the defects in the material. These hotspots can be detected through their heat radiation with an infrared camera.

A typical system consists of an infrared camera and an inductor. The inductor is positioned such that a magnetic field pulse induces currents in the test area, heating the part by a few degrees Celsius. Simultaneously the camera is recording the area. The camera captures the heat radiation, which is emitted as infrared light, and creates a temperature image of the surface.

If there are defects (cracks) in the test area, the induced current is deviated and is locally displaced or squeezed. Consequently, those locations in the part are heated more strongly. When such hotspots form directly at the surface, they emit heat radiation and are visible to the camera. The heat from hotspots within the material can also reach the surface through the heat conduction of the material. However, the range into the material is limited by the penetration depth of the induction.

The thermal recordings are analysed with video and image processing algorithms. On a thermography recording, the hotspots leave a crack signature similar to a string of pearls. In contrast, other surface features, such as roughness and scratches, are suppressed. This way cracks can be detected that would be difficult or impossible to distinguish in a conventional photo. The high contrast and characteristic shape of cracks in induction thermography images allows for reliable algorithmic detection and enables the full automation of the procedure.

Induction thermography is said to offer a particular advantage on components that have special structural properties, such as threading, gearing, blades or profiles. Suitable parts include those that are forged, sintered and additively manufactured.

www.foerstergroup.com

SLM Solutions and Mahle collaborate to offer AM for automotive part production

SLM Solutions and Mahle Group will collaborate to improve the speed and quality of automotive components in both prototype and serial production (Courtesy SLM Solutions)

SLM Solutions, Lübeck, Germany, has announced that it will collaborate with Mahle Group, Stuttgart, Germany, one of the world's largest automotive suppliers, to push metal Additive Manufacturing in the automotive sector. By joining forces, both companies hope to improve the speed and quality of automotive components in both prototype and serial production.

Mahle will use SLM metal AM machines to additively manufacture parts from aluminium and stainless steel alloys, which are resilient, corrosion resistant, and topology optimised to reduce overall weight.

"3D printing for mobility just makes sense," commented Sam O'Leary, CEO of SLM Solutions. "Our cooperation with Mahle revolutionises the production of automotive components by making them better, stronger, and lighter, not to mention more climate-neutral."

Mahle states that its AM centre in Stuttgart will play a crucial part in strengthening its role as the leading development partner for OEMs by revolutionising the pace of prototype production. The new centre will reportedly reduce production time from several months to just a few days, thereby simultaneously accelerating the drive towards climate-neutral mobility. The focus will rest primarily on components from the fields of thermal management, mechatronics, and electronics.

Michael Frick, Chairman of the Mahle Management Board (ad interim) and CFO, stated, "The development of new systems and components has to be much faster today than it was a few years ago, especially when it comes to solutions for sustainable CO_2-neutral drive systems. With our new 3D printing centre and SLM Solutions as a technology partner, Mahle is once again stepping up the pace in its strategic fields – for example, e-mobility."

It was stated that an estimated 120 SLM Solutions systems for automotive applications are already running at OEMs and Tier 1 suppliers around the world.

www.slm-solutions.com
www.mahle.com

Carpenter Technology appoints Dr Suniti Moudgil as new CTO

Carpenter Technology Corporation, Philadelphia, Pennsylvania, USA, has appointed Dr Suniti Moudgil as its new Chief Technology Officer, effective December 6, 2021. As Chief Technology Officer, Dr Moudgil will be responsible for leading the company's technology strategy and research and development organisation, as well as overseeing its intellectual property portfolio.

"With R&D expertise and a breadth of experience in technology, marketing and sales, and operations, Suniti successfully leverages cross-functional capabilities to deliver business results," stated Tony R Thene, president and CEO. "Suniti's customer focus and demonstrated ability to strategically align R&D with commercial targets positions Carpenter Technology to maintain a robust pipeline and continue to deliver innovative and value-driven R&D investments."

Prior to joining Carpenter Technology, Dr Moudgil was Global Technology Leader in DuPont's Electronics and Industrial business unit, where she led the technology strategy and R&D organisation for several product lines in the portfolio, focusing investments on markets and technologies with the greatest potential to deliver sustainable competitive advantage and revenue growth. Prior to this role, Dr Moudgil held positions at DuPont spanning R&D, product strategy, marketing and operations.

Dr Moudgil holds a PhD in Chemical Engineering from the Massachusetts Institute of Technology (MIT), with a minor in Health Sciences and Technology. She also earned her Executive Education Certification from UC Berkeley Haas School of Business on Leading Innovative Change, and is Six Sigma Black Belt certified.

www.carpentertechnology.com ■

MPIF launches PowderMet and AMPM retrospective webinar

The Metal Powders Industries Federation (MPIF) has announced a new webinar series featuring key presentations from the PowderMet2021 and AMPM2021 conferences. Beginning January, and carrying on through December, two presentations from the conferences will be available to view on the fourth Thursday of each month.

The presentations are complimentary to all MPIF member company employees. Non-MPIF members can purchase the series, or parts of the series, for a nominal fee.

www.mpif.org ■■■

MetShape additively manufactures virus model for flu research

MetShape GmbH, headquartered in Pforzheim, Germany, has additively manufactured a high-precision virus model using a Vat Photopolymerisation (VPP) process which the company refers to as Lithography-based Metal Manufacturing (LMM). This is in support of the research work of CIC nanoGUNE, the Basque Nanoscience Cooperative Research Center, on the spread of viruses and their transmission mechanisms.

Viruses are ubiquitous, particularly in winter when people are more susceptible due to the high virus load, largely from 'aerosols' (virus-laden solid or solid/liquid particles that travel in the air). A precise understanding of virus aerosols is essential in order to identify the transmission mechanisms of viruses, such as SARS-CoV-2 or influenza, and to develop solutions for prevention. The physics and chemistry of virus aerosols are investigated at CIC nanoGUNE. Research requires virus models that are as detailed, small and precise as possible. NanoGUNE works with nanoscale molecular aggregates, but increasingly uses water/virus models on the centimetre scale to complement wetting and dewetting studies on the nanoscale.

Comparison of water geometry on polymer (left) and metal (right) models (Courtesy MetShape)

One model of an influenza virus has a diameter of approximately 120 nm. Its surface consists of up to 500 'spikes', which – unlike on CoV – are only about 10 nm apart, such that tiny capillaries are located between the spikes. Liquid aerosols lose water very quickly in air; they quasi dry up. On the one hand, this can deactivate the viruses, but on the other hand, the loss of mass means a longer residence time in the air. This fine balance determines the transmission. Do the capillaries play any role?

For the centimetre-sized model, the capillaries must be less than 1 mm in size, otherwise gravity will lead to false outcomes. Such precision cannot be achieved for microparts with conventional Additive Manufacturing processes, such as Binder Jetting (BJT) and Laser Beam Powder Bed Fusion (PBF-LB). With this problem, nanoGUNE contacted AM service provider MetShape.

MetShape specialises in complex problems and metallic micro-precision parts, enabling it to support this project by additively manufacturing a high-precision virus model on the scale 250000:1. This means the model has a diameter of approximately 30 mm. The company was then able to debind and sinter the model, and provide a finished model to nanoGUNE. No post-processing steps for the virus model were required, as MetShape's technology achieved the required surface quality without the need for support structures.

Compared to a standard polymer model, the metal model performs significantly better due to the lower mass of the water, based on the smaller size of the model. Both models were hydrophilised with an adhesive spray. In the case of the polymer model, however, the resulting large water mass causes droplet artefacts, while the metal model is correctly wetted.

"Thanks to the model printed by MetShape, we can now carry out our experiments on the wetting and dewetting of water on viruses and thus achieve a new milestone in the research of virus aerosols," stated Professor Alexander Bittner. "With the new possibilities through innovative manufacturing technologies, we are taking a big step closer to our long-term goal of protecting as many people as possible from virus infections."

www.metshape.de
www.nanogune.eu

Auburn University selects PrintRite3D for several AM projects

Sigma Labs, Inc., Santa Fe, New Mexico, USA, a developer of quality assurance software for the commercial Additive Manufacturing industry, has announced that its PrintRite3D® in-process quality assurance solution will be used by Auburn University, based in Auburn, Alabama, for a number of new projects.

The solution will be installed on the university's EOS M290 machine and is the start of an academic and industrial collaboration between the university and Sigma Labs. Sigma Labs will deploy its system under a commercial lease/purchase program that provides more flexible and acceptable terms for academic institutions and early adopters.

PrintRite3D will be implemented at the Auburn University National Center for Additive Manufacturing Excellence (NCAME) to utilise additively manufactured components to improve commercial air and space travel. NCAME is funded by a $3 million grant from the Federal Aviation Administration (FAA). Its objective is to address issues related to the variability in Additive Manufacturing machines, as well as generate an understanding of how microscopic anomalies in additively manufactured metals affect overall fatigue and fracture properties.

"This is what I call the 'Achilles' heel' of Additive Manufacturing," explained NCAME director Nima Shamsaei, Philpott-WestPoint Stevens Distinguished Professor of Mechanical Engineering. "Such variations make the qualification and certification of AM materials and parts challenging. We intend to use PrintRite3D to detect anomalies during fabrication and relate them to the variations in mechanical performance of 3D printed parts."

Mark Ruport, president and CEO of Sigma Labs, commented, "We are delighted to announce our collaboration with Auburn University, and especially the opportunity to participate with the exciting partnership between NCAME, NASA, the FAA, and Auburn. These great organisations are working hard to find methods to utilise 3D printed parts to support aviation and space industries. In close coordination with the NCAME, we are also supporting the efforts of the ASTM International Additive Manufacturing Center of Excellence, with the objective of closing AM standards and workforce gaps."

www.sigmalabsinc.com
www.auburn.edu

Throughput Consulting releases powder inventory tracking module

Throughput Consulting Inc, Delafield, Wisconsin, USA, has released a new inventory tracking module to complement its existing modular suite of over twenty-five products for Additive Manufacturing efficiency and management. The Bluestreak I Bright AM™ Powder Inventory Tracking Module is said to be able to maintain full genealogy powder control from 'virgin powder' to the reclamation of AM powders after a build is complete, or the mixing of powder in R&D.

"To guarantee quality and reliability of 3D printed final products, our customers must ensure purity and consistency of powder and its reuse throughout entire AM production," stated Todd Wenzel, president of Throughput Consulting. "There are numerous physical powder changes that can occur during processes such as particle contamination and deterioration. Most likely that material is now 'out of spec', and will compromise the integrity of the final product. This is especially important in the production of aviation, medical or automotive parts that must pass stringent industry specifications and audits."

The Bright AM suite is designed exclusively for the AM environment, where the primary focus is quality processing and operations control.

www.bright-am.com

Automation boosts Additive Manufacturing production at SST

UK-based engineering solutions provider SST Technology (SST), Eynsham, Oxford, part of Polar Technology Group, has reported an increase in production after implementing automation solutions from MSP, Alnwick, Northumberland, UK, into its Additive Manufacturing division. The company states it is now producing up to seven times more parts a week, and has seen a reduction in setup time from four hours to twenty-five minutes, and halving of machining cycle times from fifteen to seven and a half hours.

Before MSP's products were introduced to SST's process, a highly skilled operator would manually locate the part in the fixture to ensure the alignment was accurate before machining. This involved multiple steps and was extremely time-consuming to achieve the necessary accuracy. Coupled with the human error caused by the manual elements, this resulted in a vast amount of machine downtime and scrapped parts.

There was also no simple way to test or adjust the accuracy of their machines to ensure they were operating to a high standard, as it involved using complex machine kinematics and the use of advanced measuring tools before machining took place, further increasing machine downtime.

"Machine downtime was, on average, five to six hours a day before MSP. 100% of my time was being used to fix issues on this project and it required an incredible amount of time from other senior level people in the business to resolve other problems – it was all hands on deck," stated Thomas Clanfield, Quality Manager at SST.

SST recently opened its advanced engineering campus in Oxfordshire (Courtesy SST)

Because it was such a time-consuming task to create a quality part, SST were having to find a balance between speed and quality: either invest more time in the manual part setup and risk the detrimental effect on productivity, or run with a poorer setup to keep up with production, but risk a heightened chance of scrapping a part.

To solve SST's first challenge, MSP's NC-PartLocator software was installed on SST's machine to automate part setup by calculating precise alignments for each machining operation. This removed the need for manual alignment, originally performed by a highly skilled operator.

"Before MSP, we were losing more parts than we were creating good parts, and we couldn't manufacture in one operation," commented Brad Airey, Operations Manager at SST. "We had to put the part on the machine, probe it, do rough cuts, measure it, put it back on the machine, re-cut it. With the introduction of MSP, not only can we remove all of these manual steps, but we can now check everything before cutting the part and resolve any problems that previously resulted in scrap parts."

The second challenge was resolved using MSP's NC-Checker software. NC-Checker ensures the machine tool's geometric performance is accurate enough for the part to be machined correctly. It produces automatic 'benchmark' reports for users to understand the performance and accuracy of the machine tool, before any machining begins.

"NC-Checker gives us the confidence to trust that our machine will always make a good part. This enables us to focus solely on the machining of the part, without having to worry about issues related to the machine itself. And this benefit is not just specific to this job, it also extends to all our future machining work and projects at SST," Airey continued.

Thomas Clanfield concluded, "Integrating MSP into the final machining process of our additive manufactured components has transformed the reliability and consistency of this process. It has also given us confidence to embark on new projects with new, similarly challenging parts, safe in the knowledge the MSP will help us achieve our goals."

MSP's NC-PartLocator software was installed on SST's machine to automate part setup (Courtesy SST)

SST has stated that automation has transformed its machine and part setup into such a simple process, that, with minimal training, novice operators are able to run the machine 24 hours a day, alongside multiple other machines. The company is now in discussions to implement MSP into their composite machining processes.

www.sstubetechnology.com
www.mspltd.com


FORWARD

University of Waterloo and Rio Tinto look to water atomised powder for low-cost Binder Jetting

The Multi-Scale Additive Manufacturing Lab (MSAM) at the University of Waterloo, Ontario, Canada, has been working closely with Rio Tinto Metal Powders, located in Sorel-Tracy, Québec, to demonstrate that metal Binder Jetting (BJT) Additive Manufacturing can be deployed as a low-cost and reliable alternative to conventional metal part production. The study has also provided a better understanding of the performance of Rio Tinto's metal powders when used in BJT.

Successful industry adoption of metal AM relies on understanding the complex interactions between design, materials and process to ensure product quality and process reliability. However, the cost of technology adoption, as well as the reliable production of high-quality, defect-free parts, can prove prohibitive. To tackle these challenges, the work has focused on reducing cost barriers by using low-cost water atomised low-alloy steel powders, and enabling robust, fast, process parameter selection and validation to obtain the desired final product quality.

The impact of this project is said to be twofold. Firstly, there is significant academic value in developing thorough process maps for BJT, where the methodology can be easily transferable to other materials and designs. Secondly, there is tremendous potential for this work to influence industrial adoption and drive forward low-cost metal AM part production. This work also has the capacity to promote BJT technology deployment in the wider Powder Metallurgy industry, thereby opening new market sectors for Rio Tinto.

For certain applications, metal BJT may seem less suitable than other metal AM techniques, due in part to comparatively lower part densities and a higher potential for geometric distortion. However, BJT has the potential to be a more cost-effective metal AM technology, when compared to Laser or Electron Beam Powder Bed Fusion (PBF-LB and PBF-EB) for example, due to its speed and scalability - enabling large batches similar to Powder Metallurgy (PM) or Metal Injection Moulding (MIM). This is an attractive incentive for BJT technology adoption in industrial applications, especially in sectors where full density is not required.

Typically, the powders used in metal AM are produced via gas or plasma atomisation, processes that result in highly spherical powders but cost more to produce than the slightly irregular water atomised powders. To leverage low-cost part production, researchers have therefore begun to explore the use of these water atomised powders in Binder Jetting.

Shrinkage resulting from the sintering stage can also be challenging to predict and compensate for. In MIM, this problem has been addressed through sintering and densification studies and approaches such as the concept of a master sinter curve (MSC), an empirical model that captures densification in response to a heat schedule. An MSC can be used to establish a map of the combined BJT process parameters and sintering schedule parameters linked to final part density outcomes. Published R&D on BJT process development and sintering has focused on producing pure Fe components, where target densities above 90% were consistently achieved, with opportunities for further improvements noted [1].

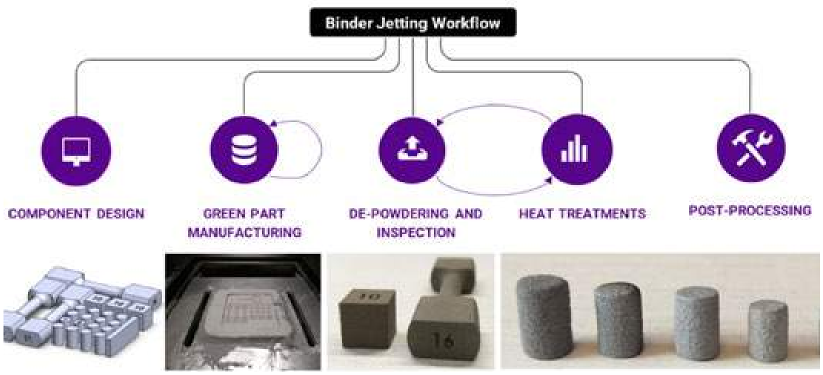
More recent work [2] has focused on constructing MSCs for BJT components manufactured via water atomised and gas atomised AISI 4340 powders, using combined stage sinter theory via dilatometry studies and validation through sintering trials. This study closely examined the densification curves of BJT parts manufactured using these powders in response to heat treatment. The study showed that the densification model can be deployed to predict the outcomes of sintering for both water and gas atomised powder BJT parts with accuracies of 91.2% and 99.4%, respectively. Microstructural examination of both categories of parts revealed similar densification behaviour.

As such, it was shown that there is a high potential for the adoption of low-cost water atomised powders for BJT, and that both the AM process and the sintering process can be tailored to achieve a similar performance to the gas atomised powders.

The ongoing collaborative research aims to provide a low-risk metal AM technology adoption roadmap, as the collaborators are actively looking to expand the feed material library available to metal AM markets. The results of this R&D programme will foster ideas on how to modify and improve the current grades of powders, as well as design new grades to be used in AM. Such collaborative work has the potential to reduce the final cost of metal AM part production.

msam.uwaterloo.ca
www.riotinto.com

[1] https://doi.org/10.1016/j.addma.2018.10.015
[2] https://doi.org/10.1016/j.addma.2021.102381



A typical workflow of Binder Jetting (Courtesy MSAM)

Fives Landis and AddUp produce stainless steel AM coolant nozzle

Fives Landis Corp., a precision grinding systems specialist and part of France's Fives Group, has collaborated with AddUp, a metal Additive Manufacturing joint venture between Fives Group and Michelin, to design and produce a custom coolant nozzle.

The nozzle design allows the flow position and shape to precisely match the challenging wheel geometry with fewer components in the assembly, while also providing optimum flow to the metal cutting zone in the grinding machine. This is said to increase the machine's performance and optimises the grind cycle.

Fives explains that using traditional production processes, fabricating this complex part is difficult and requires multiple pieces and ideal interior geometries are impossible to create. Metal AM allows this type of nozzle component to be realised from the 3D digital design to the final additively manufactured metal part in only a few steps, in a matter of days, not weeks.

AddUp teams began by laying out the part in the 3D build preparation software, AddUp Manager, then developed the best manufacturing recipe for the build, including melt strategy and build orientation, before transferring the file to the AddUp FormUp 350 Powder Bed Fusion (PBF) machine where it was additively manufactured in stainless steel.

The postprocessing operations included stress relief, wire EDM and bead blasting to complete the part, making it ready for assembly on the grinding machine. The FormUp 350 achieves up to 0.1 mm dimensional accuracy and 99.99% material density. This is said to ensure accurate and repeatable part performance without failure.

The final result is a one-piece optimised coolant nozzle that accurately delivers coolant flow into precise locations, optimising the performance of the machine.

www.fivesgroup.com
www.addupsolutions.com

The nozzle is produced on the AddUp FormUp 350 Powder Bed Fusion (PBF) machine (Courtesy Fives Landis Corp/Fives Group)

3D Metalforge to supply AM parts to Par Pacific refineries

3D Metalforge Pte Ltd, headquartered in Singapore, has signed an agreement with refining company Par Pacific Holdings, Inc., to supply a range of additively manufactured components, such as impellers, sleeves and similar parts, to Par Pacific's three US-based refineries. This builds on the successful 2021 field trial with Par Pacific and, as part of the agreement, 3D Metalforge will begin working with the company to identify and produce a range of parts that will be supplied based on Par Pacific's operational spare part requirement.

The agreement is said to represent an important step in expanding the current relationship with Par Pacific with a potential value of up to A$400,000 per annum. The agreement is exclusive, but there is said to be no minimum order value and the exact value of the contract will depend upon the operational requirements of Par Pacific during the period of the agreement.

"We are thrilled to have concluded a successful field trial and to be moving toward increased production with Par Pacific," stated Matthew Waterhouse, CEO, 3D Metalforge. "We enjoy a good working relationship with Par Pacific and look forward to continuing to support their spare part needs and help make their operations and supply chains more robust and sustainable. Once this phase of the work is complete, we will discuss the possibility of placing a production centre at their refineries to further reduce the delivery time of parts and improve supply chain sustainability."

www.3dmetalforge.com | www.parpacific.com

Short course on Atomisation for Metal Powders to return in October

After a thirty-month COVID-induced delay, Atomising Systems Ltd, Sheffield, UK, and CPF Research Ltd, have announced the return of the popular short course Atomisation for Metal Powders. The event is scheduled for October 6–7, 2022, in Manchester, UK.

The two-day course will consist of presentations from John Dunkley, chairman; Dirk Aderhold, Technical Director; Tom Williamson, Research & Development Manager, all of Atomising Systems, and Andrew Yule, Emeritus Professor, University of Manchester.

The course combines up-to-date practical information with theory and is expected to be of value to engineers working in both metal powder production and R&D. In line with the interests of many participants, the organisers have expanded the event's coverage of powder manufacture and properties for Additive Manufacturing.

An early-bird discount is available until August 10.

www.atomising.co.uk | www.cpfresearch.com

Additively manufactured heat exchanger from Eplus3D improves racecar performance

The racing team E.Stall Esslingen, of the Esslingen University of Applied Sciences, Germany, have placed fourth in the Engineering Design Competitions in Formula Student (FS) Czech and FS Alpe Adria, and first in the Efficiency Category at the FS Croatia Endurance Event. Eplus3D, Hangzhou, China, the company which additively manufactured the heat exchangers for the university's racecar, believes these wins highlight the reliability and functionality of metal Additive Manufacturing in applications requiring lightweighting and high performance standards.

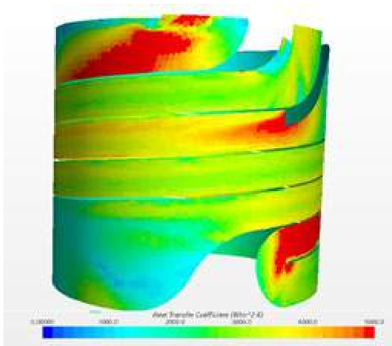
The Formula Student competition features student teams building single-seater racecars, which are then put into competition with other student designs from around the world. While speed is a factor in the judging, the driving characteristics, financial planning, and overall performance are also considered. The racing team partnered with Eplus3D to additively manufacture three aluminium components for the university's entry.

For years, E.Stall Esslingen has been a proven competitor in Formula Student. Based on the findings of the past racing seasons, the team sought to improve the reliability of its car's cooling system.

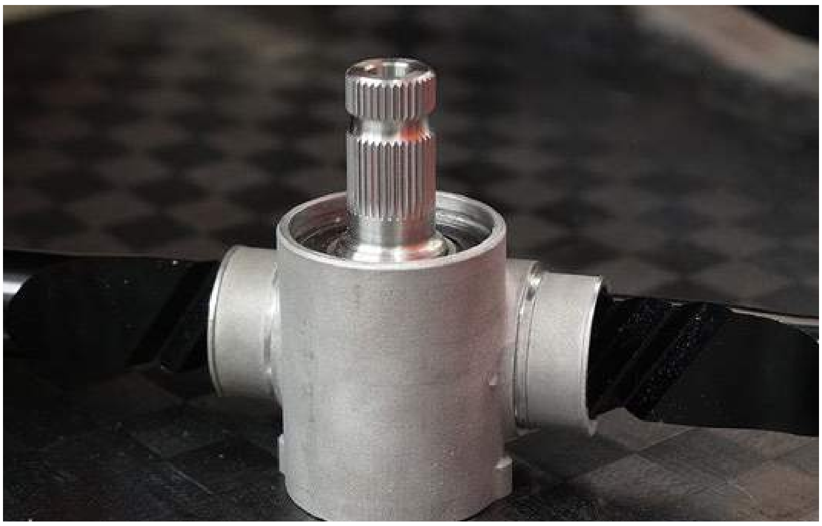
The previous cooling jacket used by the team was made of a temperature-resistant polymer, fitted directly around the electric drive, consisting of two shells. When using this cooling jacket, it was shown that, as a two-component solution, it is prone to leakage. Without sufficient cooling ability, the risk of damage occurring in the motor is quite high. Utilising its EP-M260 Dual-Laser Laser Beam Powder Bed Fusion (PBF-LB) machine, Eplus3D was able to produce a single-component aluminium cooling jacket, improving the cooling performance by enabling the entire surface of the jacket to dissipate heat.

"The 3D printed cooling jacket will be an efficient and reliable product," stated a member of the E.Stall Esslingen team. "We were able to create complex structures, which is unthinkable in any conventional way. With the help of the Eplus3D and the latest Additive Manufacturing technologies we were able to reduce the wall thickness due to the high accuracy of the 3D printer and therefore reduce the overall size of the parts."

The additively manufactured aluminium cooling jacket was said to have aided the motor of E.Stall Esslingen's racecar to stay below 65ºC (Courtesy Eplus3D)



A heat map illustrating the heat dissipation of Eplus3D's cooling jacket (Courtesy Eplus3D)



As well as the cooling jacket and plates, Eplus3D additively manufactured the housing of the steering gear (Courtesy Eplus3D)

Due to the functional integration of the cooling system, connectors and mounting, human labour is saved and the design is not prone to leakage. The minimal wall thickness of the part helps to reduce the overall diameter and, therefore, create more space for other suspension components that are based around the electric motor.

As well as the cooling jacket, Eplus3D supported the team with the manufacture of a cooling plate for the car's inverters. Both cooling parts were said to have kept the motors and inverters below 65°C, which, according to the team, is an "unbelievably good result" compared to last season's motor regularly hitting 120°C. The design of the cooling jacket allowed a simulated cooling capacity of 3.8 kW. Due to the low temperature of the components, the car is said to operate more efficiently, thus increasing the driving range.

www.eplus3d.com

Effects of shot peening on the fatigue strength of parts produced by AM

With almost sixty years of experience, FerroECOBlast® Europe, based in Dolenjske Toplice, Slovenia, is one of the global leaders in the field of surface treatment technologies. The following study, performed by the company's R&D department in collaboration with the Jožef Stefan Institute, Ljubljana, Slovenia, and Joanneum Research Centre, Graz, Austria, explores the effects of shot peening on metal parts manufactured by Additive Manufacturing.

Cold micro-forging, better known as shot peening, is a well-known surface treatment process, commonly used on machine parts in demanding industries, such as aerospace and automotive, that improves the mechanical properties of machine parts and increases their lifetime.

The question arises as to what extent the porosity and resulting micro-cracks affect the mechanical characteristics of the additively manufactured part, and what can be done to improve it. Research is being conducted into various directions: annealing and the consequential change of the metal microstructure, compression/rolling and, probably the most appropriate of all, a modern shot peening process.

Test overview

Different AM processes, and the wide range of complex parts and prototype pieces that are produced, make it difficult to select a typical machine part as a test subject. Therefore, the team chose a common test piece design, often used to perform fatigue strength tests in laboratories, for this project. The test pieces were manufactured using Laser Beam Powder Bed Fusion (PBF-LB) from three frequently used metal alloys:

- Aluminum alloy AlSi10Mg
- Maraging steel MS1 (DIN 1.2709)
- Titanium alloy Ti6Al4V

Heat treatment

The test pieces were first cleaned of residual dust and oxides before an annealing or aging heat treatment process was undertaken, as shown in Table 1.

Mechanical treatment

To ensure dimensional accuracy of the test pieces, mechanical post-processing, namely grinding, was required.

Shot peening

The final process before testing was shot peening. The selected parameters were empirically determined according to the most common parameters in practice for each particular type of conventional base material. To determine the most appropriate method, three shot peening methods with different types of shot and different intensities were selected for each tested material: Steel shot ASH110, ceramic shot Z150 and a combination of both ASH110 and Z150 for double peening (Table 2).

Fatigue strength testing

Tests for fatigue strength were first performed on test pieces that had not been treated with shot peening. The goal was to determine the load required to reach the breaking point of the test piece in 10^5 cycles and at a frequency of approximately 70 Hz. After determining the parameters, the team tested five further reference pieces not treated with shot peening, and five test pieces of each material and each type of shoot peening, resulting in a total of sixty tests.

Fig. 1 Shot peening of samples in the machine (Courtesy FerroECOBlast)

Results of fatigue strength testing

Shot peening was shown to have a positive effect on the lasting dynamic strength of the tested pieces. A reference piece, not treated with shot peening, reached breaking point in an average of 10^5 cycles, while pieces treated with shot peening survived an average of 5×10^5, and up to 2×10^6 cycles. Tests show that the number of cycles required for failure depended on the shot peening parameters, as well as on the base material of the tested piece.

Metallurgical analysis

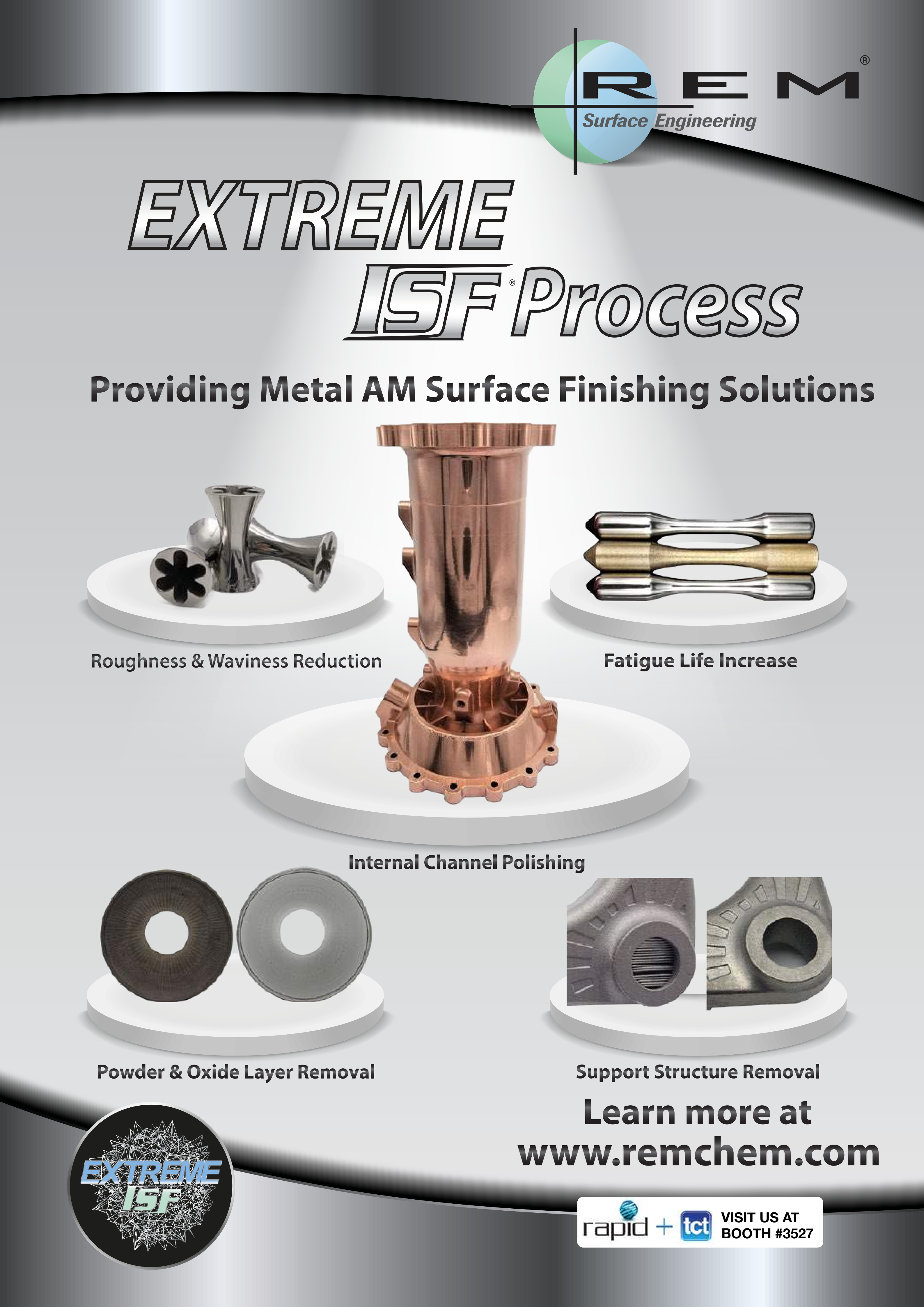
The purpose of the metallurgical analysis was to check the effect of

	Process	Temp. (°C)	Time (min)
AlSi10MG	Annealing	270	90
MS 1	Ageing	490	360
Ti6-Al4	Annealing	650	180

Table 1 Heat treatment parameters for each selected material

No. pieces	Abrasive	Intensity	Coverage	Intensity Al Si10Mg	Intensity MS1	Intensity Ti6Al4V
5	ASH110	4-7A	100%	4-7A	6-10A	6-10A
5	Z150	4-7A	100%	4-7A	4-7A	4-7A
5	ASH110 + Z150	4-7A	100+100%	4-7A	6-10A + 4-7A	6-10A + 4-7A

Table 2 Shot peening parameters for AlSi10Mg, MS1 and Ti6Al4V samples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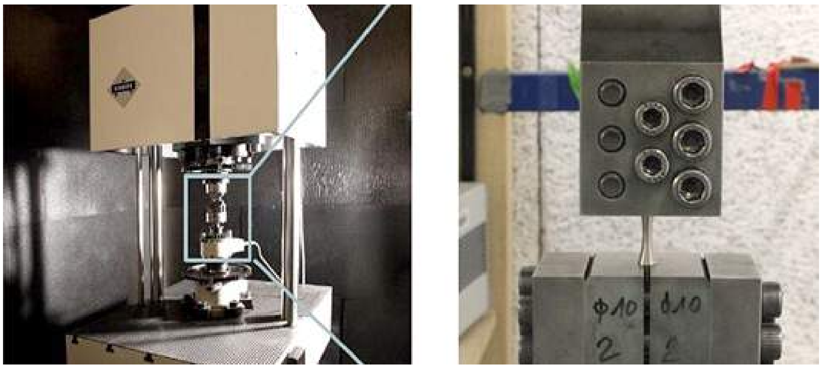
Fig. 2 Sample testing and clamping machine (Courtesy FerroECOBlast)

shot peening on the base material of the tested samples, the result of which is best reflected in the microhardness. Measurements were performed on the same kind of samples tested for sustained dynamic strength.

Summary

The results of the research confirmed a significant positive effect of shot peening on the fatigue strength of parts produced by AM, regardless of the base material.

The greatest effect was detected on the titanium alloy Ti6-Al4V, where the lifetime was extended up to twenty times. It could have been even higher, but testing was stopped at 2×10^6 cycles. Samples made of MS1 steel showed a lifetime extension of approximately fifteen times, and samples made of AlSi10Mg, where the improvement was up to around eight-ten times.

The results show the best outcome is obtained with shot peening using steel shot S110, followed by double peening with steel and ceramic shot S110 + Z150. Results for pieces made of AlSi10Mg presented the largest deviation, followed by the steel samples, while with Ti6Al4V all tested methods of shot peening produced very good results.

The effect of shot peening on the microhardness of the material was not shown to be significant. Only a slight increase of microhardness was detected on the surface and up to 200-300 µm in depth. The greatest effect was detected with double peeing with S110 + Z150, which displayed an increase of the modulus of elasticity.

It was concluded that shot peening significantly improves the mechanical properties and fatigue strength of products produced with PBF-LB processes, extending part lifetime. This gives manufacturers the opportunity to further optimise part design, reducing weight and enabling faster and more cost-effective production process and significant energy savings during operation.

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JPB Système reports significant lead time reduction using AM

JPB Système, a manufacturer of efficiency-enhancing technology solutions for aerospace, aeronautic and other industries, based in Montereau-sur-le-Jard, France, has reported extremely positive results from its continued research into the benefits and application possibilities of Additive Manufacturing. In recent trials, this has seen the business cut reported overall lead times by 80% on some parts and secure weight-savings of 30%.

"This is an important tick-in the-box for OEM customers and those further up the supply chain who are constantly seeking to reduce the overall weight of the aircraft," stated Benjamin Sangouard, Research Engineer, JPB Système. "A lighter aircraft means less fuel, which means less cost and reduced emissions, which is of course important from a sustainability perspective."

"The sustainability factor is further demonstrated by the on-demand manufacturing principle of AM that enables companies like us to produce what is needed, when it is needed, rather than traditional techniques that obligate long production runs just to ensure cost-effectiveness," continued Sangouard. "This would give us greater flexibility and reduce the need to store large quantities of stock."

The company has been trialling industrial-grade metal Binder Jetting (BJT) technology for several months as part of its ongoing objective to enable higher efficiency and agility across its production operations. The results of these trials are said to be meeting expectations, delivering robust lighter-weight alternatives quicker, easier and more cost effectively than traditional manufacturing methods. By leveraging this technology, the company is also able to create complex products with new geometries, further streamlining production efficiencies by removing the need for assembly.

"As we anticipated, our trials of [BJT] technology underscore how its versatility and ability to reduce time and costs offer huge benefits for us as a company and for our customers," stated Jocelyn Vecchio, Director of Engineering and Innovation at JPB Système.

"Such production efficiencies are evidenced if we compare the technology to the typical method of producing parts via casting in a foundry," Vecchio continued. "As well as having limitations insofar as the geometries achievable, this involves expensive tooling that can entail long lead times of around six months – even longer if geometries change and a new mould is required. In contrast, using [BJT] Additive Manufacturing, we could produce the same part in about four weeks; that's a decrease in time of more than 80%, which ultimately means we speed up delivery times to customers. The flexibility of this technology also means that, it doesn't take any longer to produce 100 different parts than it would 100 identical parts."

JPB Système has also noted benefits from the way in which AM enables greater design freedom to produce complex products much more easily. This includes the consolidation of two parts into one, or products that accommodate one element inside another – something not typically achievable with conventional manufacturing techniques.

In one example, this allowed the team to produce an assembled multi-component functional system that offers multiple advantages by incorporating three components into one. Thanks to a reduced number of parts, the supply chain is simplified and assembly time is removed. From a safety aspect, the eventuality of foreign object damage to the engine is all but eliminated.

JPB Système has expressed its intention to open a start-of-the-art facility in Villaroche in 2023, which is partly government funded through an initiative designed to accelerate industry growth and help manufacturing companies. The eventual integration of AM is expected to underpin the new facility's automated production lines, once operational.

"So far, our exploration into the application possibilities of [BJT] have proved very successful and offer significant potential in our quest to innovate our production processes to better meet the needs of our customers," Vecchio concluded.

www.jpb-systeme.com

AM's ability to create parts that match the durability of traditional parts, while using less material, has seen JPB enjoy up to 30% weight savings (Courtesy JPB Système)

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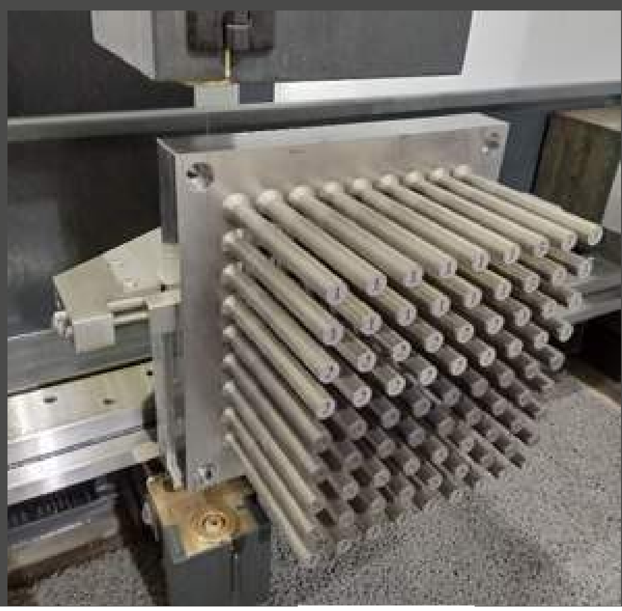

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Development of $1000 Wire Arc AM machine

Engineering researchers from California State University, Los Angeles, USA, and Eskisehir Osmangazi University, Turkey, have published 'Development of a Low-Cost Wire Arc Additive Manufacturing System' in the Journal of Manufacturing and Materials Processing. The paper outlines the joint development of a Wire Arc AM (WAAM) machine – intended for the development and repair of high-value components – which can be built for around $1,000.

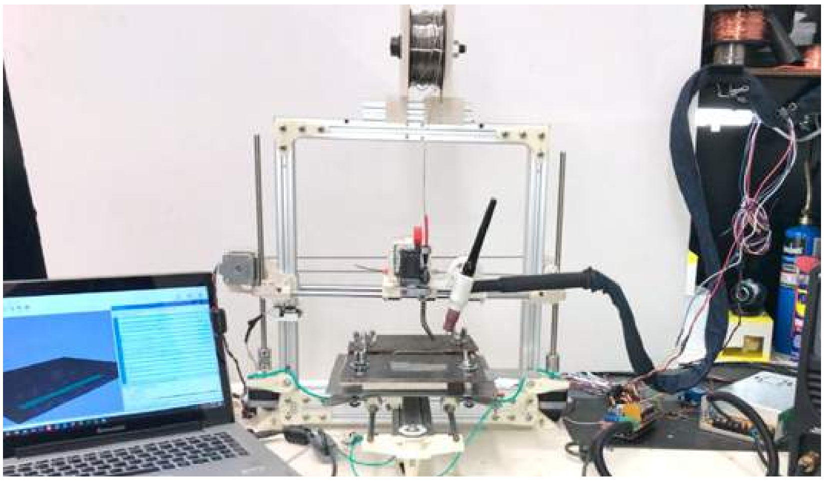
Traditionally, the WAAM machine, a type of Directed Energy Deposition (DED) technology, utilises complex robotic arms and expensive CNC equipment to precisely position components. This paper aimed to demonstrate that a standard gantry system, typical of Fused Deposition Modelling (FDM) machines, can be utilised to manufacture an affordable option for metal AM.

The gantry system used in these experiments was inspired by an open-source design known as Bukobot, which features z-axis vertical square frame and a perpendicular x-y axis carriage. All process controls and programming of the system (i.e., host, firmware, slicer, and modelling software) were based on an open-source architecture. Plain carbon steel AISI 1030 and Inconel 718 wires were selected to test the systems, pushed through a melt pool into a custom-made automated wire feeder. Preliminary testing consisted of selecting ideal parameters for AISI 1030, with settings based on wire-feed speed, torch travel speed and electrical current. After single-pass tests for each parameter set and material, multi-pass tests were performed.

While some limitations were noted (e.g., limited environmental protection of the metal build from the atmosphere), many are addressable by customisation (using an enclosed inert gas-filled chamber around the build). With proper parameter selection, the paper states that the system can process a variety of metals – such as titanium and alloys, nickel- and cobalt-based superalloys, and low-alloy steels – with less effort and at lower cost than Powder Bed Fusion (PBF) systems.

'Development of a Low-Cost Wire Arc Additive Manufacturing System' was written by Miguel Navarro, Amer Matar, and Mohsen Eshraghi of California State University and Seyid Fehmi Diltemiz of Eskisehir Osmangazi University.

www.calstatela.edu
www.ogu.edu.tr



Assembly of the gantry-based WAAM system components (Courtesy Navarro, M; Matar, A; Diltemiz, SF; Eshraghi, M, 'Development of a Low-Cost Wire Arc Additive Manufacturing System' JMMP)

Freemelt receives machine order from the University of Texas

Freemelt, Mölndal, Sweden, has received an order for a Freemelt ONE Additive Manufacturing machine from the University of Texas in El Paso, USA. The machine will be used for materials research and is scheduled to be delivered during the first quarter of 2022.

"The acquisition of the Freemelt ONE open-source Electron Beam Powder Bed Fusion system will expand the existing capabilities in the W.M. Keck Center for 3D Innovation at UTEP, to propel research in various aspects of Additive Manufacturing, including new materials and monitoring, and furthering opportunities for students to engage in research experiences," stated César A Terrazas-Nájera, Assistant Professor of Research.

Freemelt explains that the order from the University of Texas is the second to the US in a short time, signifying a great deal of interest in the company products in North America, which is now one of the its main markets.

Ulric Ljungblad, CEO of Freemelt, commented, "The University of Texas is a leader in 3D printing and, therefore, one of the most sought-after universities to have as a customer. The fact that they see the benefits of our solution to enable their research and development of materials bodes well for our future in the North American market."

www.freemelt.com

Guide to PM microstructures updated and expanded

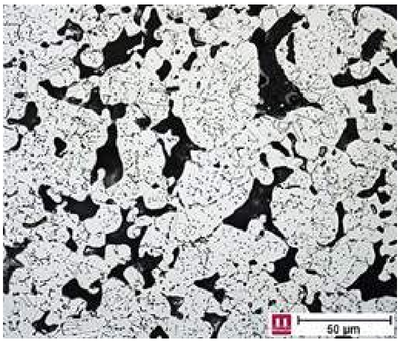
The Metal Powder Industries Federation (MPIF)'s Powder Metallurgy Microstructures Database has been updated to include new materials (including 300 and 400 series stainless steel alloys) and to streamline the user experience.

Designed to assist metal powder-based parts manufacturers and end-users in interpreting Powder Metallurgy microstructures, the database intends to build an appreciation for what a powerful tool Powder Metallurgy can be when engineering new components, designing new materials and solving quality problems.

Using the database, users are able to reference materials processed by conventional and elevated-temperature sintering, accelerated cooling rates and other properties to determine the phases and structures of the materials. Specimen preparation and proper selection of etchants are also covered.

Powder Metallurgy microstructures differ from wrought materials in two ways, reports the MPIF. The major difference is the presence of pores which will vary in size, shape, and distribution depending on density, alloy system, and processing method. Another difference is due to the PM alloy systems themselves. Many PM alloys take advantage of admixed alloy additions, such as copper and nickel in steel alloys, which may or may not result in a completely homogeneous microstructure. The lack of homogeneity has been found to be advantageous in many cases. Due to the inherent flexibility of alloying methods in PM, dual phase, heterogeneous or composite microstructures are quite common and responsible for the unique properties of these materials.

www.mpif.org



Micrograph of the newly-added stainless steel – 300 series alloy as found in the MPIF's Microstructures Database (Courtesy MPIF)

Making the unmakeable: How metal AM is bringing the aerospike rocket engine to life

The history book of engineering is filled with concepts that failed to achieve success because they were ahead of their time. This was almost the case for the aerospike rocket engine, recognised in the 1950s as a strong concept and tested by NASA in the 1980s and 1990s, but found to demand too much of the manufacturing and materials technology available at the time. *Metal AM* magazine spoke with Pangea Aerospace and Aenium Engineering about reinventing the aerospike for the 21st century, and how Additive Manufacturing allowed them to 'make the unmakeable' – pushing their expertise in AM, materials science and Design for AM to its limits in the process.

Aerospike rocket engines were first conceived in the 1950s as a high-performance alternative to more traditional bell nozzle configurations. However, the shutdown of major space programmes, together with the manufacturing effort associated with their complexity, led to a period of relatively low research and industrialisation effort. Recently, aerospike engines have experienced a resurgence of interest because of their altitude adaptation properties and advantageous performance characteristics compared to bell nozzles. Furthermore, the ongoing maturity level of Additive Manufacturing processes and materials for propulsion applications makes it possible to build an economically viable aerospike engine with reduced lead time.

Two European companies based in Spain, Pangea Aerospace, and Aenium Engineering, are working together to advance the aerospike concept for the 21st century through a focus on nozzle design, advanced AM processing and post-processing, as well as exploring material science and metallurgical approaches on new high-performance copper alloys to resist the harsh heat flux/mechanical strength requirements of this application. The alliance between both these companies has resulted in a breakthrough in aerospike rocket engines and the firing of the first liquid oxygen/liquid methane (LOX/LNG) dual regeneratively cooled aerospike to be additively manufactured in history. DemoP1 packs 20 kN (~2 tons) of thrust in just above the dimensions of a football. It does that thanks to a combustion chamber pressure in excess of 50 bar and a near-stoichiometric mixture ratio, yielding a hot and energetic flame causing heat fluxes in the walls up to 50 MW/m^2. These numbers make DemoP1 an ambitious demonstrator to design and operate, especially at this small scale where cooling

Fig. 1 A close up view of Pangea Aerospace's aerospike engine (DemoP1) (Courtesy Pangea Aerospace)

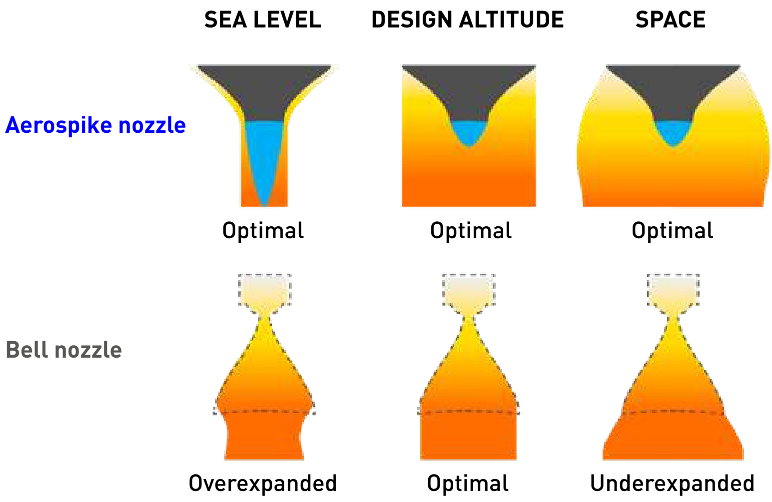


Fig. 2 Comparison between an aerospike and a bell nozzle (Courtesy Pangea Aerospace)

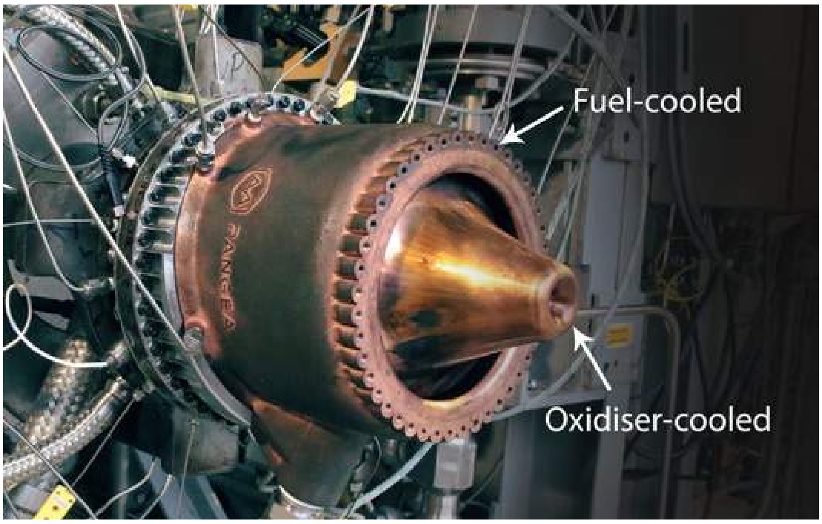


Fig. 3 Pangea Aerospace's engine in the test bench at DLR's Lampoldshausen facility after the first firing of a series of nine firings. DemoP1's regenerative cooling uses both the fuel and the oxidiser (Courtesy Pangea Aerospace)

requirements are the most stringent. The parameters of DemoP1 do not fall short of those found in some modern operational engines. To give an idea, if DemoP1 would be attached to a small launcher weighing around 1.5 tons, it could easily reach the threshold of space, topping at 120 km.

Explaining the benefits of the aerospike engine concept, Federico Rossi, Head of Propulsion & co-founder of Pangea Aerospace, stated, "The aerospike concept is considered the 'holy grail' of rocket propulsion because of aerodynamic altitude adaptation. Typically, modern rockets employ a bell-shaped nozzle to convert thermal energy into pressure and kinetic energy and propel the spacecraft against gravitational forces. Aerospike engines carry out this process more efficiently." The plume exiting a bell nozzle, composed of hot combustion products, behaves differently depending on the altitude at which the rocket is flying. "When the rocket is lifting off from sea level, ambient pressure is high and the plume is forced to compress as soon as it exits the solid walls of the bell. In this condition, the bell nozzle is referred to as 'overexpanded' because its exit pressure is lower than the ambient pressure in the lower parts of the atmosphere." This condition is intuitively associated with a suboptimal performance level and the overexpansion can be so severe as to cause air flow to enter the nozzle, causing asymmetric flow separation and sudden nozzle structural failure.

As the rocket climbs, bell nozzle performance increases until reaching design altitude, where the exit pressure is equal to the pressure of the surrounding ambient. This condition is referred to as 'optimal expansion', and is associated with the one trajectory point where this nozzle operates at peak efficiency. When it has climbed past this point, the nozzle enters the 'underexpanded condition', where its performance keeps increasing simply because of the reduction in the surrounding ambient pressure (Fig 2).

"An aerospike nozzle encounters the same operating conditions throughout its trajectory, but its geometry gives the plume the intrinsic tendency to 'self-tune' to an optimal expansion condition. Especially at sea level, the flow from an aerospike immediately 'feels' the higher ambient pressure and, as a consequence, is squeezed against the walls of the nozzle, thus compressing and increasing its pressure to match that of the ambient." This increase in pressure, applied on the nozzle walls, results in a higher thrust force pushing the nozzle along its direction of motion.

The aerospike, when compared to a bell, benefits from this increase in thrust from sea level to roughly the altitude of optimal expansion. In terms of trajectory, this typically means the first 10 km of the rocket ascent, when the vehicle is heaviest (thus the highest thrust is required to accelerate it against gravity). This finally yields to a more efficient nozzle when it is needed, and makes the aerospike 10–15% more efficient than its bell counterpart for vehicles in the micro-launcher class. For larger scales, the aerospike can be made even larger, up to the point where its performance gain approaches 20%. With the remaining rocket parameters being constant, this equates to a payload increase of the same magnitude or even higher.

Propulsion and the role of cooling channels

"One of the most important design parameters affecting the performance of an aerospike and, in general, of rocket nozzles, is the expansion ratio: a measure of how much the nozzle allows the flow to expand," Rossi continues. "The higher the expansion ratio, the larger and longer the nozzle becomes. A high expansion ratio is usually desirable for bell nozzles, because the engine, although it works less efficiently at sea level, will maximise its performance at higher altitudes. For an aerospike, this is even more important, because efficiency at sea level is retained, even with a high expansion ratio, as the flow will still behave optimally. Therefore, for an aerospike nozzle, it makes sense to have the highest possible expansion ratio."

What, then, prevents a designer from building an aerospike engine with a very high expansion ratio? "Dimension is one key factor," stated Rossi, "but the most notable factor is cooling requirements. In fact, a high expansion ratio leads to a bigger nozzle, and – uniquely for the aerospike – it also leads to a bigger engine overall. A bigger engine has a higher surface area to cool, and, historically, this has been one of the major drawbacks impeding the large-scale adoption of aerospike engines in the industry."

Rocket engines need to be actively cooled because the flame temperature inside their combustion chamber exceeds 3000 K – enough to melt or sublimate practically all construction materials. A popular method for mitigating the wall temperature of the engine is referred to as 'regenerative cooling.' This strategy entails circulating one of the two propellants (typically the fuel) in small channels within the engine walls. In these cavities, the fuel flows at high speed, cooling the walls, prior to its injection in the combustion chamber, where it burns with the other propellant: the oxidiser. The oxidiser is typically not used in regenerative cooling because it tends to attack and corrode the walls of the cooling channels. Too often, the oxidiser can burst into flames due to tiny sparks generated by impurities in the channels, or when exceeding the material autoignition temperature.

Fig. 4 The DemoP1 is the first additively manufactured aerospike engine in the world to be powered by liquid methane and liquid oxygen (Courtesy Pangea Aerospace)

The reality, however, is that the amount of heat generated by an aerospike is so high that using a classical regenerative cooling strategy would not be enough at a system level. For this reason, Pangea Aerospace leveraged Additive Manufacturing and advanced simulation tools to design and apply a unique regenerative cooling strategy.

DemoP1: Bringing AM to the aerospike

DemoP1, shown in Fig. 4, is the first additively manufactured aerospike engine in the world to be powered by liquid oxygen and liquid methane. "We took advantage of the dual-wall construction, unique to toroidal aerospikes, to split the cooling system in two circuits," explained Rossi. "The 'pointy' end, called the plug or spike (the latter giving the engine its name), is cooled with liquid oxygen (the oxidiser), while the external housing is cooled with liquid methane (the fuel).

Fig. 5 The machined inner surface of the DemoP1's outer section, or jacket, with cooling channels visible (Courtesy Pangea Aerospace)

In this way, the classic drawback of aerospikes becomes an advantage. First of all, we make use of both propellants, that are fed to the engine at cryogenic temperatures (around -170°C), to take away the heat from the structure. Hence, the enthalpy rise of the entire propellant mass flow rate is fully exploited to keep the engine cool."

"Secondly, the heat exchanged with the engine drives the propellants to a higher temperature, which makes the injection and combustion process more efficient," Rossi continued. "Combustion efficiency further increases the thrust of the engine. Furthermore, using both propellants to cool the engine means that less energy needs to be imparted to each one of them, relaxing the requirements on the pressurisation system and leading to a lighter structure overall."

"The aerospike engine has better performance than bell nozzles, but also brings with it several complexities. To solve those problems, we have pushed AM to its limit. This means that we designed the components specifically for AM."

However, tailoring the cooling system to achieve such a feat was no easy task. "Propellants inside the cooling system enter in the liquid state, then undergo a pseudo phase change and leave the channel in a supercritical state. During this process, the properties of the coolant vary sharply, so that taming the fluid to extract the maximum cooling efficiency requires a novel approach for channel design." In fact, typical cooling channels are traditionally milled in the engine wall in the form of rectangular slots. There are a certain number of channels starting from the base of the nozzle, and their geometry simply follows the engine contour, while changing in width and height.

The geometry of the aerospike does not allow for this simple approach, partly because of its higher heat generation, but also because of its simple geometrical characteristics. Hence, Pangea decided to 'make a virtue out of a necessity' and adopted what it calls a pointwise optimisation. "Practically, we optimised every single tiny segment that makes up the channel. This is where Additive Manufacturing shines on DemoP1, because this type of complexity really does come for free in AM; our channels resemble shapes that are found in nature, rather than straight lines," Rossi said. "The sharp property variation of the coolant requires an equally sharp variation in channel geometry to avoid overcooling or overheating of the material. With our approach, we were able to split the complex cooling problem into many tiny segments and address every single segment for maximum efficiency. This basically means getting close to the material maximum operational temperature at every segment. Whenever you try to overcool the engine, that is pressure that is lost in the channel, hence overcooling must be kept to a minimum."

Fig. 6 DemoP1's jacket in the PBF-LB build chamber (Courtesy Aenium Engineering)

"Unfortunately, controlling subsonic fluid dynamics is less straightforward than optimising segments in series, because what happens downstream has an influence on what is happening upstream. Hence, the optimisation process had to be iterated several times and cross-checked with state-of-the-art CFD models. The implementation of CFD analyses allowed us to further play with this virtually unlimited design freedom by introducing roughness and curvature into the equation."

Because of its geometry and the direction of the coolant flow, the curvature of a classic channel would play a negative role on DemoP1. To mitigate this effect, Pangea introduced artificial curvature on a different plane in the form of a spiral. The spiral shape of the channels on DemoP1 forces the coolant against the walls by centrifugal action, further increasing heat transfer efficiency.

More importantly, roughness, taken alone, is probably the variable with the largest effect on both heat transfer and pressure drop. It is well known that the surface finish of additively manufactured parts can be poor. "If roughness has no purpose in your application, the surface finish must be improved. For us, roughness is of utmost importance to increase heat transfer in the most critical areas. We worked with our partner, Aenium, to modify the roughness level during the build process, as well as exploiting the natural roughness variation of additively manufactured structures by exacerbating the overhang angle in the most critical areas."

Last, but not least, the first portion of the channel is sized in such a way that the coolant reaches the most critical areas around the so called pseudo-critical state, where its cooling properties peak in the high-roughness environment.

Design for AM: planning for advanced manufacturing & post-processing

Additive Manufacturing is a relatively new and advanced manufacturing technology with its own unique drawbacks, benefits, and post-processing requirements.

The aerospike engine's improved performance is achieved at the cost of structural complexity because of the presence of the additional spike structure in the middle of the combustion chamber. Moreover, the rocket engines currently in use are assembled using hundreds or thousands of parts, and therefore have numerous assembly steps, joining operations and surfaces to be sealed. This results in high manufacturing costs and often reduced functionality. Dr Zsombor Sápi, Structural Engineer at Pangea Aerospace stated, "We used Additive Manufacturing and

Fig. 7 Part of Pangea Aerospace's propulsion team. From left to right: Gabrielle Esnault, Artem Demediuk, Federico Rossi, Adrià Argemí, Nicola Palumbo and Zsombor Sápi (Courtesy Pangea Aerospace)

pushed the technology to its limits by integrating all these components into two main parts: the internal 'plug', which also houses the injector head, and an external housing. This not only enabled us to simplify the assembly and joining of the engine, but also provided tools to improve other aspects of the structure. We could reduce the weight, fine tune the load paths acting inside the engine and provide better access to the telemetry system."

Besides its structural complexity, the thermal management of an aerospike is also challenging. The structure features not one, but two combustion chamber surfaces that are subjected to hot gases and need to be cooled with the same amount of propellant. This demanded the development of a complex system of internal manifolds and cooling channels. The channels have various orientations and cross-sections and are interleaving the structure in a way that conventional subtractive manufacturing processes would simply be unable to deliver.

"Of course, the drawback of the design freedom offered by AM is the constraints set by the Powder Bed Fusion (PBF) manufacturing process. Therefore, the layout of the engine was developed from day one accounting for Design for Additive Manufacturing (DfAM) principles, taking into account the constraints in terms of size and tolerances dictated by design choices and CFD analyses. One of the most important aspects is the necessity of powder removal.

"We used Additive Manufacturing and pushed the technology to its limits by integrating all these components into two main parts: the internal 'plug', which also houses the injector head, and an external housing. This not only enabled us to simplify the assembly and joining of the engine, but also provided tools to improve other aspects of the structure."

This is particularly critical in a rocket engine because a blocked cooling channel can cause the failure of the propulsion system."

"Several powder removal openings have been integrated into the structure and various post processing steps and cleaning operations were utilised to ensure the cleanliness of the components. The other challenging field was the printability of overhang surfaces and their correlation with surface roughness. These design constraints set the basis for several iterations between the propulsion (functional) – design – structural analysis - and manufacturing departments of Pangea Aerospace, finally leading to a design ready for printing," explained Sápi.

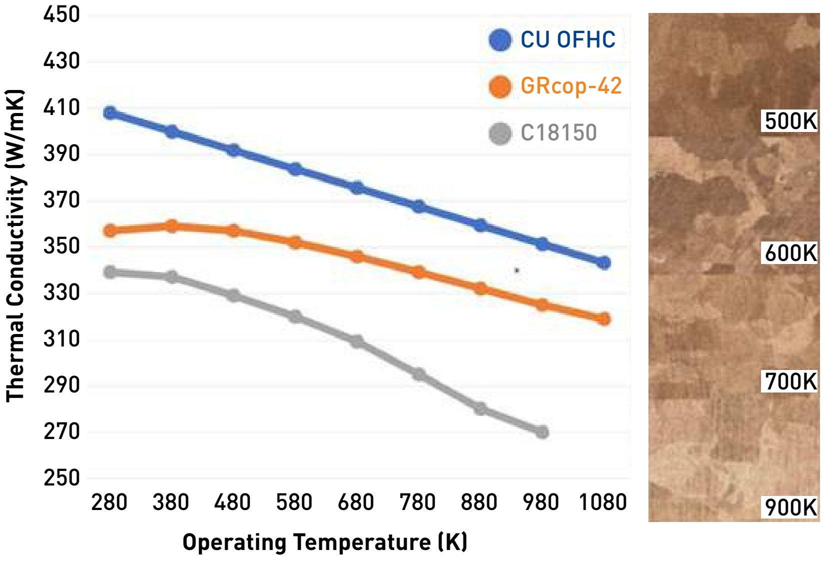


Fig. 8 Thermal conductivity of the GRCop42 alloy versus other alloys at different operating temperatures (Courtesy Aenium Engineering)

Material engineering and GRCop42

Additive Manufacturing processes have been widely used as a rapid prototyping method and cost-effective solution for low-volume serial production, but few people have explored AM's potential as a tool by which to address the most challenging of metallurgical needs, or considered the benefits AM offers in terms of a new approach from materials engineering.

"In our development of critical TRL9 devices for the space launch sector, we faced numerous material engineering challenges and had the opportunity to solve them through a combination of AM and complex post-processing. The use of nickel alloys such as IN718, IN 625, Invar36, Haynes 282 and Rene 41 is common in this sector, and we internally qualified these materials, all of which demonstrated outstanding performance, in their strengthened condition, when exposed to demanding thermomechanical properties at creep. High temperatures, pressures, acceptable conditions under low Total Mass Loss (TML) outgassing, low Coefficient of linear Thermal Expansion (CTE) and corrosion resistance are some of the advantages of using nickel alloys for space applications. Nevertheless, during qualification they demonstrated low thermal conductivity, preventing full evacuation of heat flux and promoting component failure in its steady state, on top of experiencing hydrogen embrittlement effects," stated Miguel Ampudia, Chief Innovation Officer at Aenium Engineering.

Copper alloys offer a thermal conductivity twenty times higher than the nickel alloys listed above and experience no H-embrittlement effects, but have lower mechanical properties and are prone to corrosion when exposed to harsh environments. Developed by the team at NASA's Glenn Research Centre, GRCop42 (CuCrNb) is a complex and advanced alloy capable of surviving high-strength, high-heat flux and harsh environments at high temperatures, making it perfect for regeneratively cooled rocket engines and other applications.

Commonly, the environment and boundary conditions are the factors that place the highest demands on the materials used in a rocket chamber. After supporting complex transitory states, the steady state is defined by high temperatures, extreme thermal gradients, high pressures and direct contact with the propellants and their combustion radicals. For these types of applications, an extra level of awareness is necessary to minimise the material's exposure to combustion radicals and fully understand plasticity-based cycles.

Pangea and Aenium based all of their qualification procedures and material/process characterisation on the following material properties/behaviours, which represent the main failure factors in these applications:

- Material creep
- Low-cycle thermal fatigue (LCTF)
- Corrosion behaviour

"During steady-state operation, the chamber liners are one of the most challenging geometries in terms of material science. These thin surfaces (less than 2 mm thick) separate the liquid cryogenic propellants, flowing in the cooling channels at a temperature around 100 K, from the combustion chamber, where the temperature exceeds 3000 K. This, in combination with the pressure in the cooling channels, which is higher than 100 bar, and the thermal cycles the material is exposed to, leads to a special temperature-plasticity-based phenomenon called Low-Cycle Thermal Fatigue (LCTF), which is one of the dominant failure modes in rocket engines. In this kind of

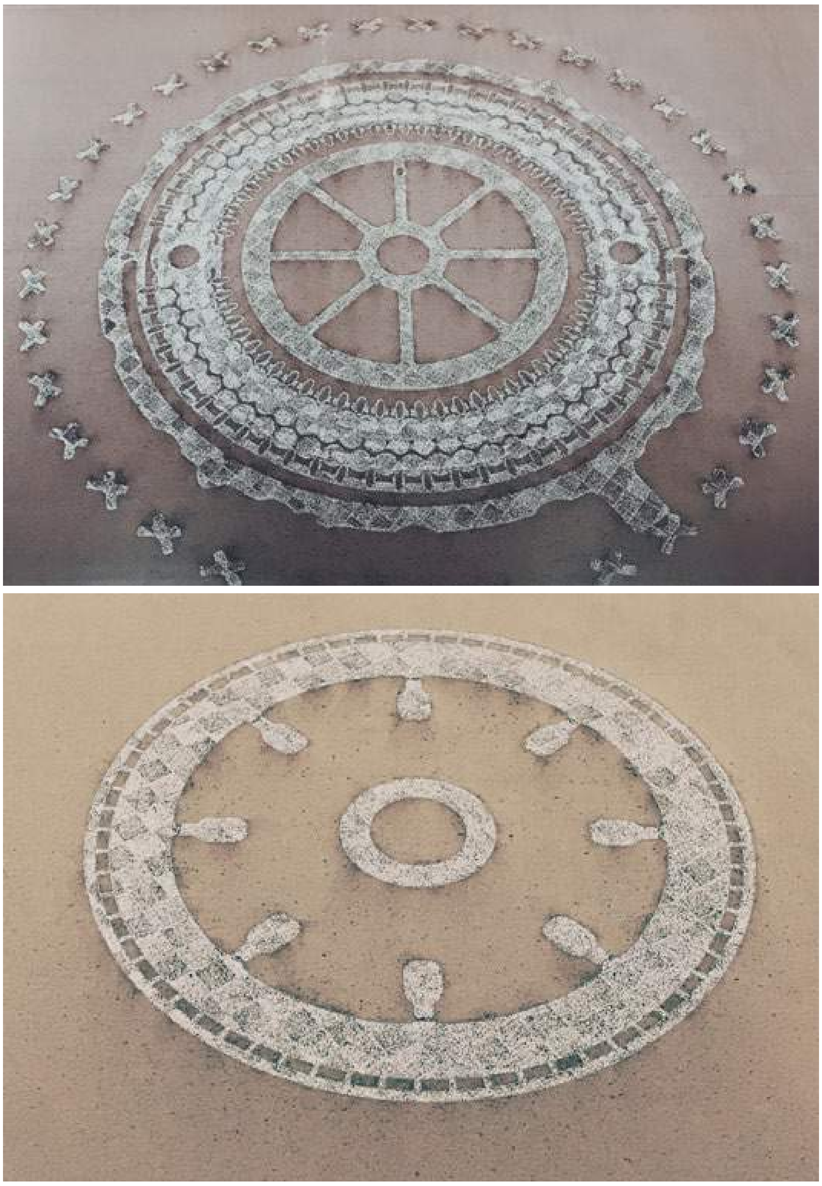


Fig. 9 Build chamber views showing sections of the cooling channels employed in the aerospike engine (Courtesy Aenium Engineering)

thermal fatigue, the cyclic deformation is imposed as the result of the constrained differential thermal expansion within a solid caused by temperature gradients induced during alternate heating and cooling in the steady state operation of the engine. For this reason, the microstructure and metallurgical properties of the liners must be specially prepared for a stable cycle, without changing their conditions because of the operating time or cycles."

As mentioned, GRCop42, when correctly 'microstructure-programmed' during processing and post-processing, offers almost stable mechanical and thermal properties, demonstrating better results in this phase than the Ni-base alloys. These, on the contrary, experience microstructure modifications with the thermal cycles induced by engine operation, as well as during the sharp start-up and shutdown transients.

"Additively manufactured and post-processed GRCop42 showed an almost pure copper matrix, yielding excellent thermal conductivity. At the same time, the alloy strength is increased even at high working temperatures thanks to its chromium-niobium intermetallics. Our team led a six-month qualification procedure addressing the most advanced thermomechanical behaviours and establishing multi-parameter procedures for processing and post-processing the alloy under the most demanding certification requirements to meet all of the process needs," stated Nicola Palumbo, Head of Mechanical Engineering & co-founder of Pangea Aerospace.

"Compared to our other AM-qualified Cu alloys, such as C18150 (CuCrZr) and pure copper (OFHC), GRCop42 demonstrated outstanding thermal conductivity at high temperatures and mechanical properties during creep, maintaining almost stable grain size and strength as opposed to C18150 properties, which decreased with the working temperature."

Hundreds of different testing probes defined by different ASTM standards in certified laboratory-controlled conditions, and their subsequent analysis, were necessary for the whole understanding of additively manufactured GRCop42 alloy and its definition as one of the ideal materials for the demanding working conditions of a rocket engine combustion chamber.

Processing the aerospike using PBF-LB at Aenium

Commenting on the build of the aerospike engine, Miguel Ampudia explained, "The processing and qualification of Cu alloys through PBF-LB can introduce numerous processing challenges. Our teams already possessed extensive experience in TRL9 manufacturing of Cu alloys such as C18150 for flight components on combustion chambers, satellite and launcher applications, but GRCop42 presented numerous challenges that made it necessary to modify the hardware for the process and adopt some new material engineering approaches."

Aenium's core business is materials science and complex processing though PBF and other techniques for the space and energy sectors, among others. "Our team developed a method called Multi-volume Laser Energy Density [M-VLED], based on our applied material science knowledge with laser systems and AM. Through this method, using its in-house processing and lab capabilities, our team is able to dynamically modify laser energy density based on the controlled cooling ratios achieved on the powder bed or melt pool."

"Controlling energy density and cooling ratios accurately enables infinite possibilities around microstructural programming of the part, offering the ability to provide different thermomechanical properties as needed, in just one part. Based on a deep technical study of the alloys we work with, we define the microstructure and its subsequent part properties, achieving changes in specific areas and on specific surfaces without introducing porosity."

Through this method, it is possible to create or dilute intermetallics and show and hide some phases or microconstituents, which allows the building of a part using multiple process parameters dynamically controlled in specific areas or surfaces where changes to its mechanical/thermal properties are needed. This requires the qualification of multiple M-VLED parameters and special Hot Isostatic Pressing (HIP) strategies during post-processing.

"Depending on the alloy, M-VLED enables us to precisely program parts with multiple areas of yield strength, UTS, elongation at break, thermal conductivity, hardness, surface roughness, residual stress and many others, voxel by voxel." stated Ampudia. "Creating thermal bridge effects, non-conductive shells, different LCTF behaviours, decreasing part of the post-processing efforts and controlling the residual stress across the part are some of the advantages of using this technique."

For the whole qualification and production phase, Aenium used EOS PBF-LB machines and numerous types of pre- and post-processing equipment, as well as metallurgy and inspection processes for the powder and the manufactured certification samples. The critical aspects when qualifying GRCop42 for the aerospike's production were established as:

- Microstructure management and laser control in PBF-LB
- Hardware modifications and special process conditions
- Raw material quality and handling
- Intensive post-processing

"The PBF-LB process introduces a wide range of process variables that determine the metallurgical properties of the final part. Some of these variables are atmosphere, energy density, cooling ratio, layer deposition method, rheology and powder characterisation. The accurate control of all of these variables is what decides the process results. Commonly, process stability changes depending on the area or build plate position. This represents a challenge when applying the M-VLED procedure to control microstructure. It is known that gas flow distribution is not 100% homogeneous across the built plate – even more so in large-format PBF-LB machines – and even laser variables slightly change during a build due to optics and laser module lifetime," stated Ampudia.

"To apply M-VLED, these factors were precisely measured and controlled in real-time, enabling precise control of the multiple parameters and volumes involved. By achieving high cooling ratios, driven

Fig. 10 Additively manufactured augmented spark igniter (ASI), providing the initial flame to start the combustion process inside the main chamber of DemoP1 (Courtesy Pangea Aerospace)

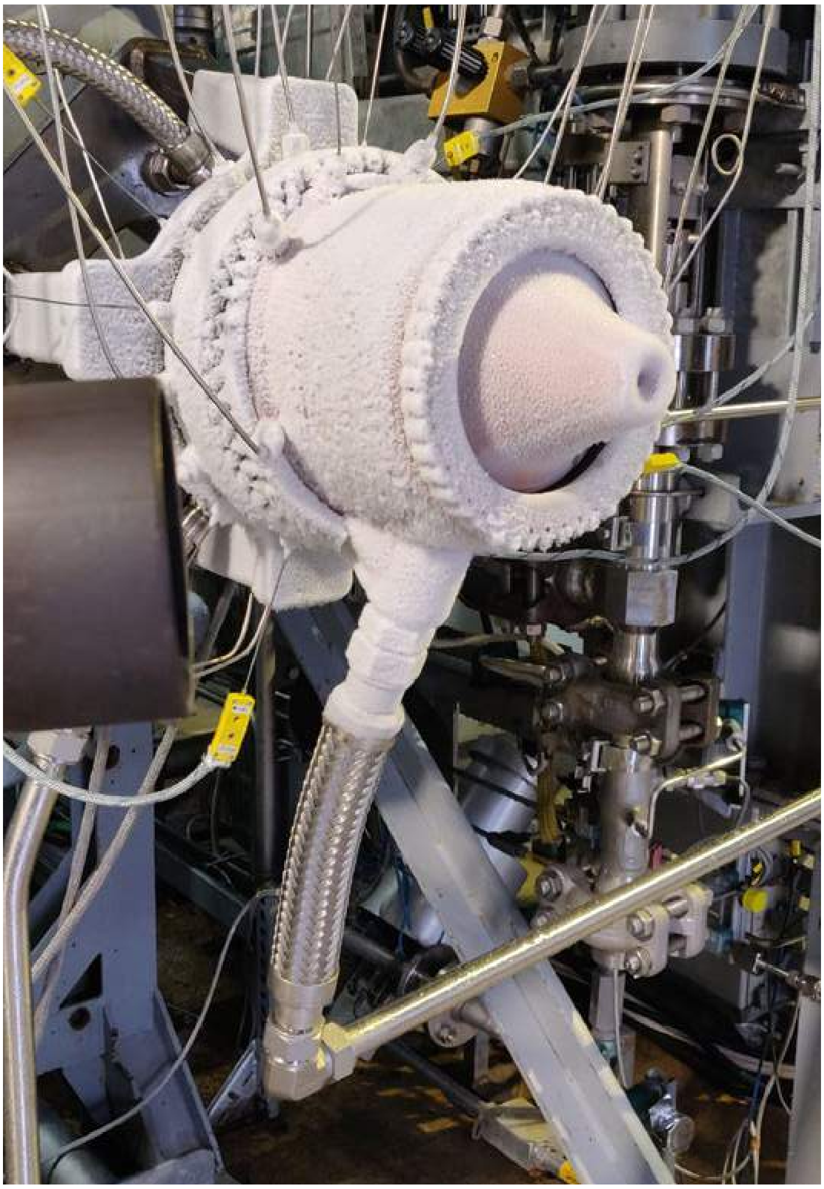


Fig. 11 The DemoP1 aerospike engine after initial cold-flow checks at the P8.2 high-pressure facility in Lampoldshausen, Germany (Courtesy Pangea Aerospace)

by the energy density applied by the laser and optics, the result of this process decision was to qualify the manufacturing process under He gas in the chamber. This demonstrated better results, improving the management of Cr2Nb precipitated elements compared with Ar atmosphere."

The build plate was precisely studied to avoid diffusion problems on the first layers, and enhanced thermal control and heat distribution was achieved using a special platform which remains confidential. Powder distribution on the build plate and its flowability also represented some challenges. Particle distribution was tested and parameterised, and finally defined through different batches, but, even then, the best results were obtained when modifying the recoating system to increase flowability, using thermal methods that currently remain confidential. These modifications were required to increase the stability and homogeneity of the process.

"As important as the defined pre-processing and AM processing are, this study also required detailed and accurate post-processing. Some challenges were presented by the need to maintain the desired microstructure despite extensive post-processing requirements that included high-pressure cycles, thermal cycles and other chemical and e-chemical methods for roughness treatment over the aerospike's channels and injectors," concluded Ampudia.

After these R&D, testing and qualification procedures were complete, the alloy and process were ready for the first component to be built, certified and enter production.

Post-processing

The inaccessibility of the unique cooling channels in the aerospike engine meant that a different approach to depowdering was required. Pangea and Aenium used the most advanced techniques to be sure the final dimensions were compliant with requirements. Using this information, the liner, the most critical part of the engine, was accurately machined.

Nicola Palumbo explained, "One of the biggest challenges presented by AM when it comes to designing a single-piece part with integral features such as cooling channels and liner, inlet and outlet manifolds, sensor ports, attachment flanges and stiffening supports, is the removal of powder entrapped within the channels during the AM process, as no access to the interior is available. This is important because, as already mentioned, no residual powder is permitted by the engine requirements. The same is valid for chips, burrs and scrap material produced during machining, polishing and corrosion protection post-processing; if not removed, they could be detrimental and lead to the failure of the engine during the firing. Moreover, the cleaning itself must not contaminate the engine or reactivate any corrosion mechanism."

"Given the inherent geometric complexity of an aerospike engine and its extremely complicated cooling channels, it is no trivial matter to achieve this goal in a simple, efficient, inexpensive and feasible manner. And, more seriously, failure to do so could result in a show-stopper," stated Palumbo.

"To be sure that no debris is left in the engine after post-processing, a particular system of evacuation channels and ports, with the minimum number of operations possible, has been designed for both the external case and the plug. These were designed into the part from the beginning to the very end of the manufacturing process, proving that if 'Design for AM' is correctly approached from the very beginning, even the most challenging projects can be achieved by implementing relatively easy operations."

The liner is one of the most important parts of a rocket engine, as it allows the proper thermal exchange between the hot gas side and the coolant side, preventing the construction material from melting down. This is possible only if its final dimensions and surface roughness are compliant with very tight requirements. It is well known that one of the drawbacks of AM is that the production of 'perfect' parts is impossible, due to the distortions that occur during the building of the part and the poor surface roughness when compared to other manufacturing methods.

Palumbo stated, "This usually leads to the production of a liner which does not have a uniform thickness, with differing material distribution along the part presenting multiple crack initiation sites all over its surface. At Pangea Aerospace, we designed the aerospike keeping in mind, from scratch, this important requirement. To overcome this problem and create a uniform liner, the parts went through a series of post-processes involving CAD-CAE-3D scan-Computed Tomography that ultimately resulted in a very accurately machined part within the tight tolerances required. This was made possible thanks to an initial design effort considering all processes in the production chain, which enabled the post-processing of the engine without the need for expensive tooling, reducing cost and lead time. This again confirms how Additive Manufacturing is the perfect candidate for a complex engine like the aerospike."

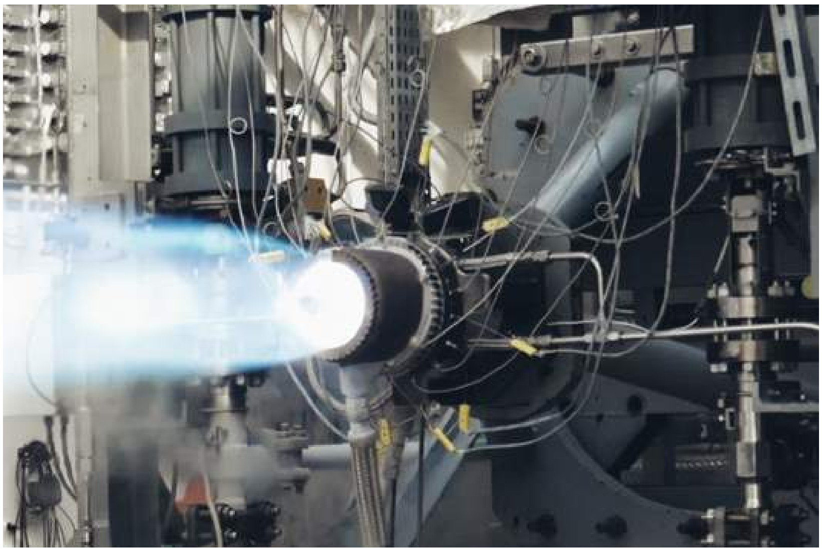


Fig. 12 A DemoP1 'hot run' in Lampoldshausen (Courtesy Pangea Aerospace)

Test firing demonstrates aerospike's viability

The DemoP1 aerospike engine was tested at the P8.2 high-pressure facility in Lampoldshausen, Germany, one of the few facilities in the world capable of testing methalox rocket engines of this size. The test campaign was performed over a span of one month, totalling seven cold-flow checks and ten hot runs. Cold-flow checks are extremely important for an additively manufactured part of this complexity, because the AM process still has limited repeatability compared to the standard processes used to produce rocket engines. Hence, the hydraulic resistance of the entire thrust chamber needs to be carefully characterised before moving to the hot fire phase.

Federico Rossi commented, "Hot runs have been performed in incremental steps, starting from the classic 'burp' test and concluding with three consecutive runs of more than one minute, with the last hitting 160 seconds. The first short runs were useful for characterising the initial transient and tune the timing of valve openings. In total, there are six valves onboard the engine that control the mass flowrates of the main propellants and of the propellants for the ignition system. These had to be carefully timed to obtain a smooth but fast start-up and to ensure survival of the ignition system during operation of the main combustion chamber. The latter runs were full-duration steady-state tests, useful to ensure repeatability of the combustion process and investigate how the engine's structure and performance react to changes in the design parameters. The engine has been tested across and outside its design operational envelope, changing feed system parameters 'on the fly' during the same hot run." Fig. 12 shows an aerospike engine in steady-state operation.

One of the most important takeaways from the engine test campaign was the characterisation of the engine's reusability. For this reason, it was fundamental to monitor the engine wall temperature through the different firing cycles (cold-hot-

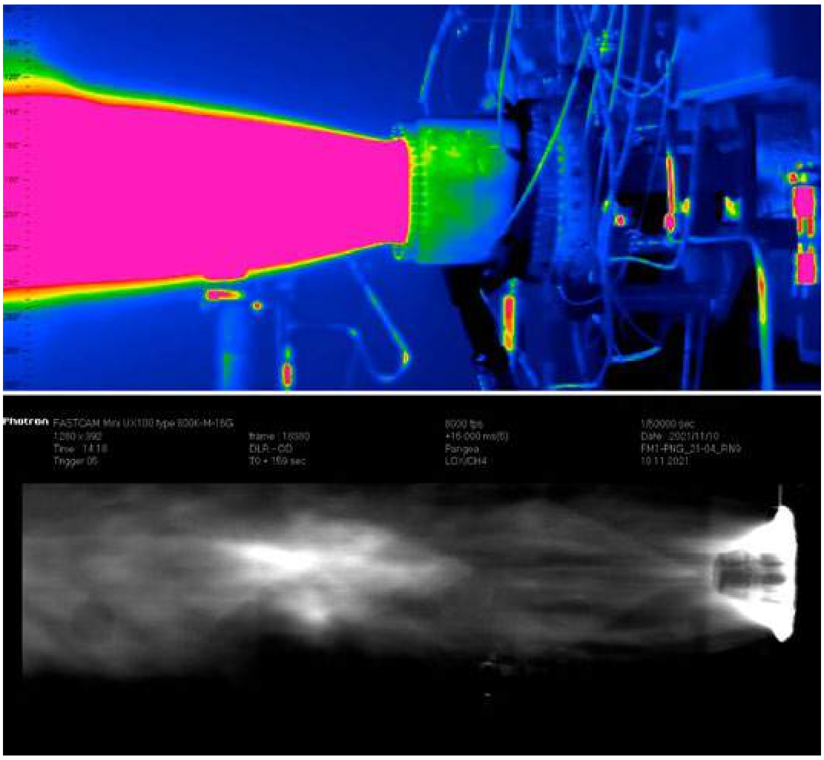


Fig. 13 Vital parameters of the engine's hot fires were monitored with pressure and temperature sensors, together with a thermal camera and a high speed camera (Courtesy Pangea Aerospace)

cold), triggering low-cycle fatigue: the main mechanism responsible for early engine failure. The vital parameters of the engine were monitored with pressure and temperature sensors, together with a thermal camera whose output is shown in Fig. 13.

The next stage of the journey

Leveraging the technologies demonstrated during the development of DemoP1, Pangea Aerospace is starting the development of our first commercial engine, named Arcos. This uses the same architecture and materials as DemoP1, but with a massive increase in dimensions and performance. "Arcos will bring the aerospike concept to its full potential by adopting a very large expansion ratio, maximising performance and compactness by allocating the turbopump assembly (TPA) inside the toroidal aerospike," stated Rossi.

The project partners are also researching advanced microstructures for corrosive and demanding boundary conditions using nano-alloyed GRCop-42 Cn-Ts. "We have clearly demonstrated the advantages of using material science as an innovation driver for the space sector, and the GRCop42 alloy has been established as one of the most challenging and interesting alloys in the market for addressing the boundary conditions offered by regeneratively cooled rocket engines. Nevertheless, our consortium is now focused on carrying all these innovations to the next step at TRL9, with the first commercial aerospike Arcos developed by Pangea Aerospace. Aenium will bring to the consortium the next level of materials engineering through the development of multi-material chambers," stated Miguel Ampudia.

"By combining the excellent and proven properties of GRCop42 alloy, the performance of nickel and a third refractory alloy, the consortium is now developing the next techniques and procedures for achieving bimaterial and trimaterial interfaces, providing the combustion chambers with the best properties of each material alloy by volume, all of which will have M-VLED techniques applied to them. The coming months will also bring to light new alloys as a focus for development, based on the collaboration agreement achieved by Aenium with one of the most innovative powder brands in the USA; Powder Alloy Corporation, Ohio, which will bring to the consortium the most advanced methods for creating new performance alloys ready for processing, developed ad-hoc to suit the needs of the multi-material parts."

Currently, both teams are obtaining the first qualification process and material results as a starting point for the next generation of rocket engines with the technology that will bring into life the first commercial aerospike rocket engine flying, achieved through the intelligent combination of Additive Manufacturing and material science.

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Seurat Technologies: Evolving AM to finally out-compete conventional manufacturing

Every so often, something comes along that gets the whole Additive Manufacturing industry talking. Over the past two years, few companies have generated as much intrigue as Seurat Technologies, the Lawrence Livermore National Laboratory spin-out named for the French pointillist, bringing with it a technology roadmap that promises to evolve metal AM to the crucial point of out-competing conventional manufacturing methods. In this *Metal AM* exclusive, James DeMuth, Seurat CEO, offers the deepest look yet into the technology behind his company's promise.

Manufacturing needs to change to evolve. While Additive Manufacturing has held the promise of bringing about change, it has not, to date, delivered on two fronts. Firstly, goods continue to be cheaper to buy when manufactured on the other side of the world. The current economy incentivises the offshoring of not just manufacturing, but skilled labour, which takes jobs and technical expertise away from local industry. Manufacturing must become domestic, regional, or local, and AM provides the key to unlock this opportunity.

Secondly, manufacturing continues to be a major producer of greenhouse gases, with toxic fuels burned to make and transport goods. Adopting reuse, recycling, and reducing initiatives is a positive change, but becoming carbon-free will usher in the next manufacturing era. While AM has made steps in this area, it has yet to become a carbon-free solution.

Additive Manufacturing has the potential to reinvent how parts are made. So far, however, it has mostly been used as an alternative for high-value applications in niche markets. This limited scope of influence is a problem: the existing technologies are not hitting the necessary price points, production rates, and quality measures to truly disrupt the conventional manufacturing market.

Seurat Technologies has plotted the course to change the future of manufacturing by leveraging next-gen technology and going to market as a parts producer. The company's name is inspired by French artist Georges Seurat (pronounced Sur-rah), the originator of the pointillist style. In pointillism, complete images emerge from small, distinct dots of colour that blend in the viewer's eye. Using the same basic principle, but with

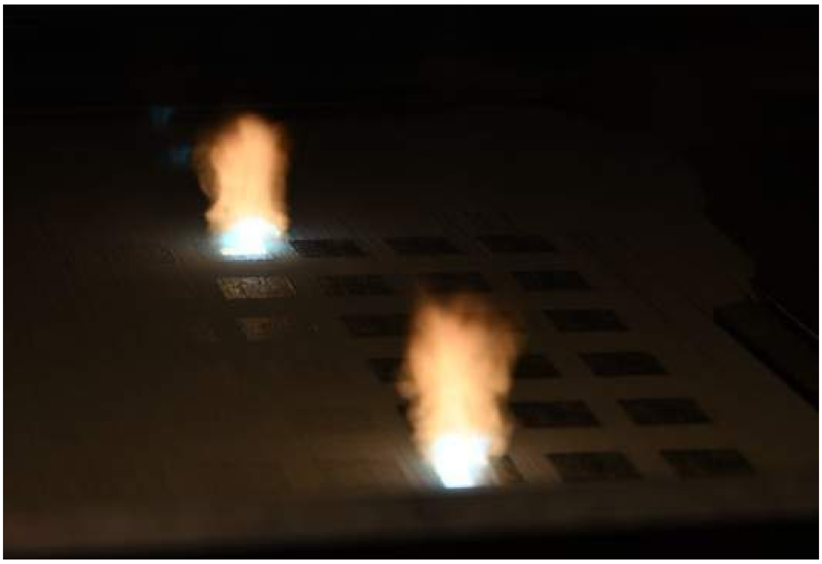

Fig. 1 In Area Printing, a vapour plume vaporises material and ejects it away from the melt pool

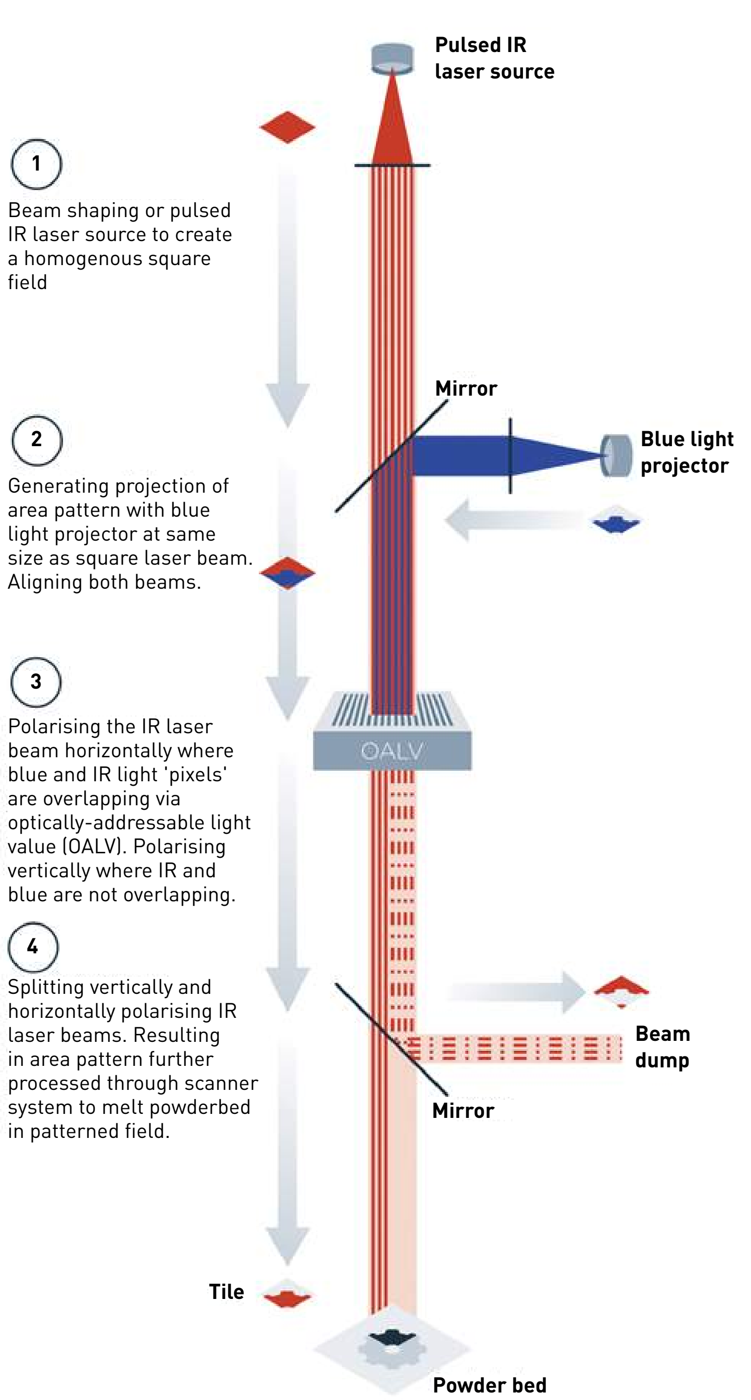

Fig. 2 An infographic illustrating Seurat's Area Printing technology

laser energy and powdered materials instead of paint and canvas, Seurat's Area Printing™ technology (pictured in action, Fig. 2) creates objects by 'connecting the dots' to bring a new perspective to the Additive Manufacturing industry.

Using this technology, Seurat's mission is to democratise Additive Manufacturing by scaling it such that it out-competes conventional manufacturing processes such as machining, casting and forging, all on a per-price basis – while maintaining all the benefits of AM. In addition, Seurat's AM process is powered by 100% renewable energy, thereby offsetting CO_2 emissions from traditionally 'dirty' processes, such as casting.

These are big claims for a new Additive Manufacturing company, but this startup is backed by decades of laser and optics development across the giants of the US national laboratory system, leveraging techniques that, when applied to Additive Manufacturing, result in massive scalability in per-part economics. One of the titans behind Seurat is Lawrence Livermore National Laboratory (LLNL), which developed Seurat's Area Printing technology in late 2011 to address metal Additive Manufacturing deficiencies that revealed themselves when working on a nuclear fusion energy project. To harness and contain the energy of 192 high-powered lasers, LLNL researchers needed a fusion chamber that could withstand intense thermal loads and thermal fatigue. Although AM could deliver the design complexity and speciality material required, the time required to build the fusion chamber was estimated to be over two centuries!

Surrounded by sophisticated laser technology and some of the brightest minds in the field, Seurat embarked on the development of what is now called Area Printing with the intent of removing the AM throughput barrier. In 2015, the company spun out of LLNL with an exclusive licence to the patented technology. It is now running its beta machine, employs fifty-eight staff, has filed more than 160 patent and trademark applications, and has received $79 million in funding from nine venture partners.

Area Printing breaks through the barriers that impede other solutions, allowing metal Additive Manufacturing to become practical, feasible, and desirable for a broad range of applications currently served by traditional manufacturing. With unparalleled scalability and unit economics at or below those of conventional methods, Seurat can facilitate change in supply chains and decarbonise manufacturing while delivering all the advantages of AM, such as lightweighting, optimisation, inventory reduction, etc.

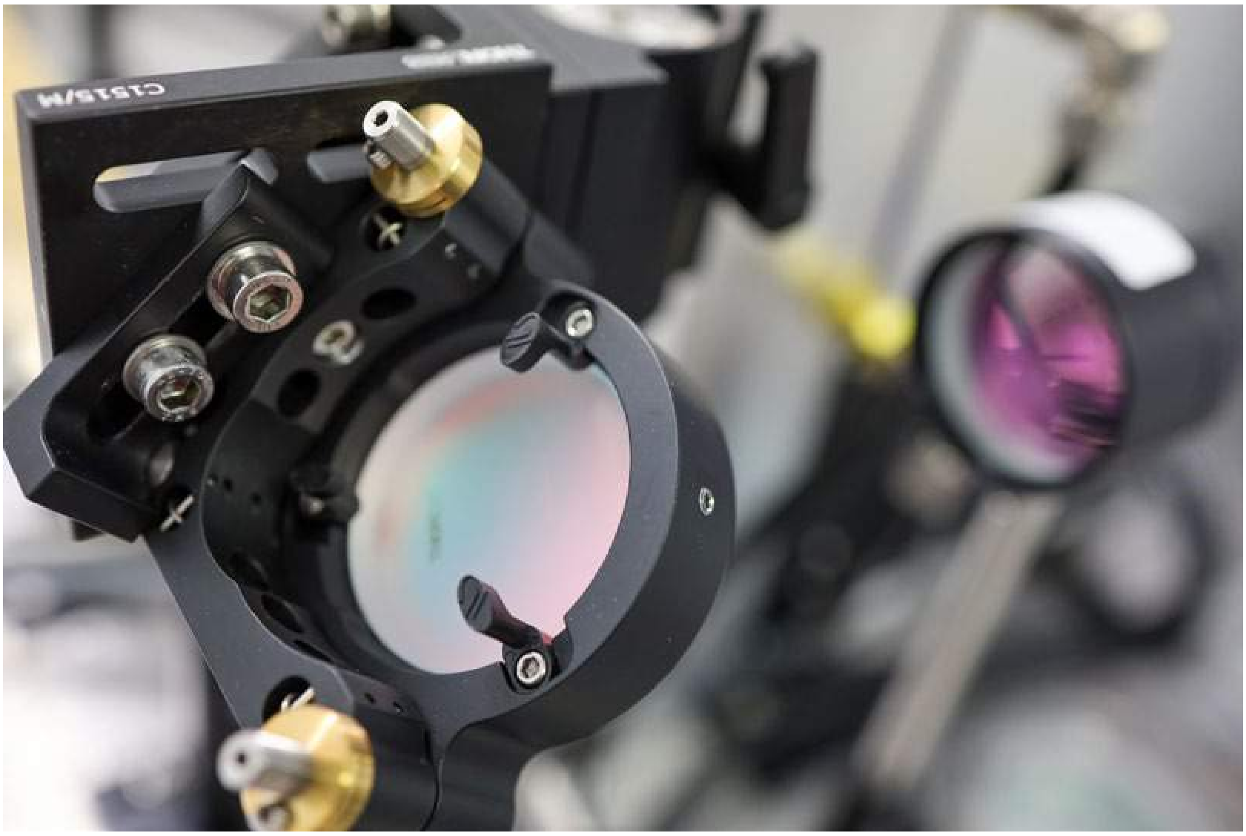

Fig. 3 Vertical stage mirror as part of the Seurat optical transport system

How does Area Printing work?

Area Printing currently employs a modular laser source that generates high-energy, pulsed IR output in the range of 30 kW (future generations will use even higher laser outputs to accelerate throughput). Beam shaping transforms the output into a homogeneous, uniform, square field. The next operation is projecting a pattern of low-intensity, blue laser light onto the square IR laser beam. The blue-light pattern represents the part geometry in the exposure area, much like that used in polymer Direct Laser Printing (DLP). In Seurat's Gen 1 machine, the pattern uses 2.3 million pixels and, within each tile, each pixel is always perfectly aligned. An infographic illustrating the process is shown in Fig. 2.

"... Beam shaping transforms the output into a homogeneous, uniform, square field. The next operation is projecting a pattern of low-intensity, blue laser light onto the square IR laser beam."

The intersection of IR and blue light is the precursor to creating an 'on/off' condition, meaning that the laser energy will be directed to the powder bed to melt powders in the prescribed pattern. Using a polarising rotation mirror, the IR field with embedded blue light assumes a positive, vertically oriented state, while the excluded regions become horizontally oriented. The polarised beam then passes through an optically aligned light valve (OALV), which directs the positive-state laser energy to the powder bed and dumps the unwanted portion of the IR beam. This process is repeated forty times per second to melt powder in forty unique tiles, in a single second.

The use of the terms 'on' and 'off' states for the IR delivery is misleading, however; Area Printing isn't a binary process. Grayscale imaging can be performed at the blue-laser pattern-generation step to adjust the energy delivered to each pixel. This capability provides control over heating and cooling during the build, which can be leveraged to address distortion, manipulate grain structure, adjust material properties, improve surface finish and reduce (or eliminate) support structures, all on a per-pixel basis.

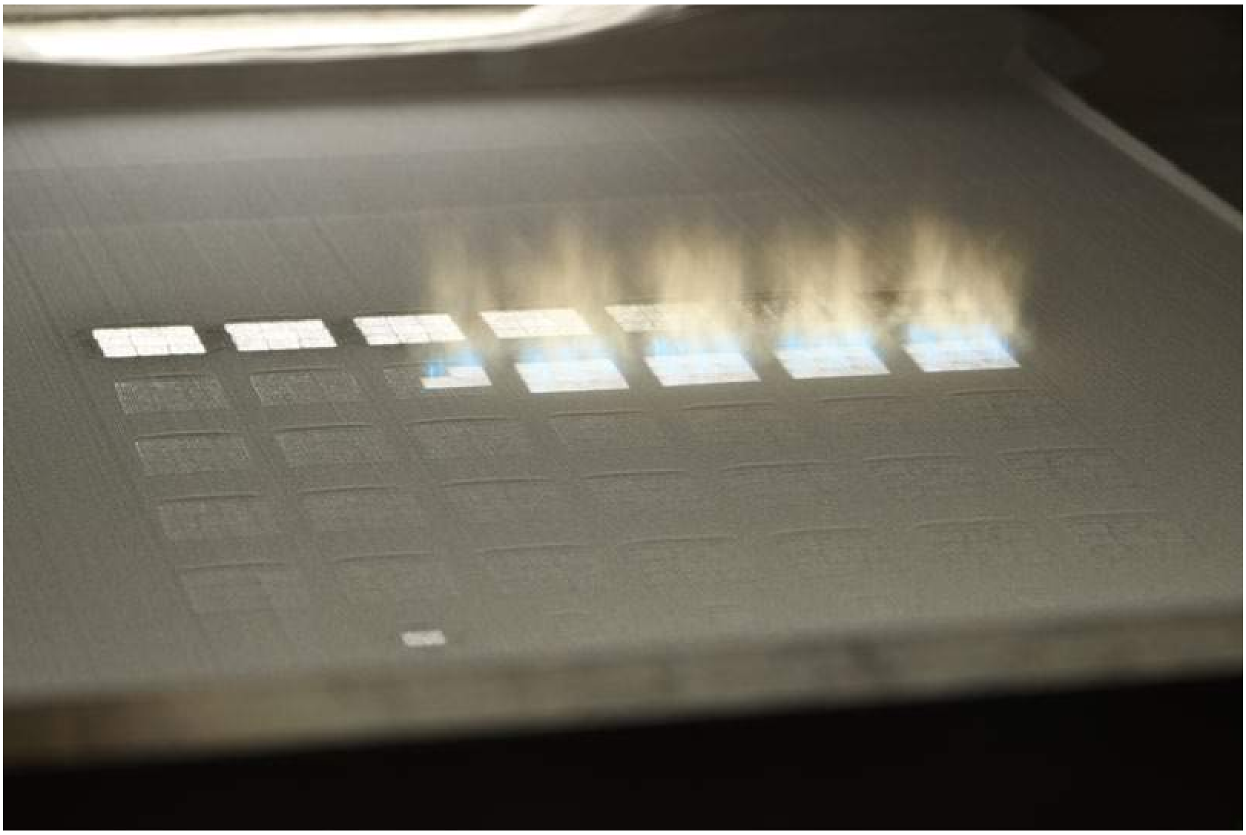

Fig. 4 Area Printing prints one tile next to the other. Over 2.3 million pixels are used to define the shape of each tile achieving a pixel size of 6–10 µm, which exceeds the current xy-resolution of PBF-LB systems by far

Why AM scalability is so challenging

The key to making Seurat's promises a reality is that, in Area Printing, throughput is independent of resolution. Conversely, with the established Powder Bed Fusion (PBF) and Directed Energy Deposition (DED) technologies on the market, breaking that connection gets complicated and scalability is impeded. Throughput rates for PBF and DED – as well as Area Printing – are a function of the amount of laser energy put into the machine. But with PBF and DED, it isn't as simple as increasing laser power to make parts faster; if power is increased while maintaining focus, these technologies drive futher into the key-hole melting regime, and as they progress above the optimum energy density (W/mm^2), they become subtractive laser-drilling operations. There have traditionally been two options to increase throughput with higher laser power: use a larger spot size, or use multiple laser spots. The first option destroys resolution, and the second complicates the process while diminishing the return with every laser added.

"The key to making Seurat's promises a reality is that, in Area Printing, throughput is independent of resolution. Conversely, with the established PBF and DED technologies on the market, breaking that connection gets complicated, and scalability is impeded."

In a single-laser solution, the barrier is that spot size is proportional to the laser's power. So, if a laser's wattage increases by 400%, the illuminated area also increases by 400%. Instead of the usual 80 µm spot, parts would be built with a 160 µm resolution. The outcome is a larger minimum feature size and more postprocessing. To have more laser energy and preserve the 80 µm spot, the solution has been to use multiple lasers with lower power, making the system more complex.

However, the throughput issue here is that four, eight, or twelve lasers do not deliver melting speeds four, eight or twelve times faster, because they simply can't operate as efficiently as a single laser. The reason for this is that each laser beam must avoid the plume of smoke and soot emitted by other beams; soot plumes readily absorb laser energy, which can result in unwelded or partially welded areas. The highly choreographed beam interactions necessary dictate that all lasers cannot operate at anywhere near full output. Further, in currently available PBF-LB machines, a lot of surface tension is created by the melting process, which can create beaded molten material; this unwanted material will then fuse to the part geometry and can compromise part quality.

Area Printing is a Powder Bed Fusion technology with a different approach, which enables it to deliver both high throughput and high resolution. The first-generation production system (Gen 1) will use 30 kW of laser energy to make metal parts by embedding the laser beams with a 6–10 µm resolution (at the bed). Using 10–150 times the power of a competitive single-laser technology, Area Printing delivers optimal energy density by patterning the beam, which distributes the laser's power over a prescribed area defined by millions of individually controllable pixels. Staying within the optimal power density range while controlling heating and cooling rates also minimises smoke, soot and spatter, all of which routinely cause build defects and errors. This has always been a significant issue in series production.

Fig. 5 Andy Bayramian, Seurat's Chief Scientist, adjusts the waveplate to complete an optics upgrade on Seurat's R&D machine

	2022 Gen 1	Gen 2	Gen X
Resolution (features/mm)	10	14	20
Layer thickness (µm)	25	25	25
Throughput (kg/h)	3	30	1700
Price ($/kg)	< $300	< $150	< $25
Build volume (m)	0.45 x 0.45 x 0.45	1.2 x 1.2 x 1.2	9.6 x 9.6 x 9.6

Table 1 Area Printing's scalability supports simultaneous improvements in resolution, throughput, unit economics and build volume

Area Printing roadmap

Area Printing technology uses a highly scalable architecture that facilitates improvements in throughput, cost and quality without compromise (Table 1). This technology roadmap is well defined through the next decade, allowing for a steady progression down the $/kg cost curve. The

"Area Printing is a Powder Bed Fusion technology with a different approach, which enables it to deliver both high throughput and high resolution."

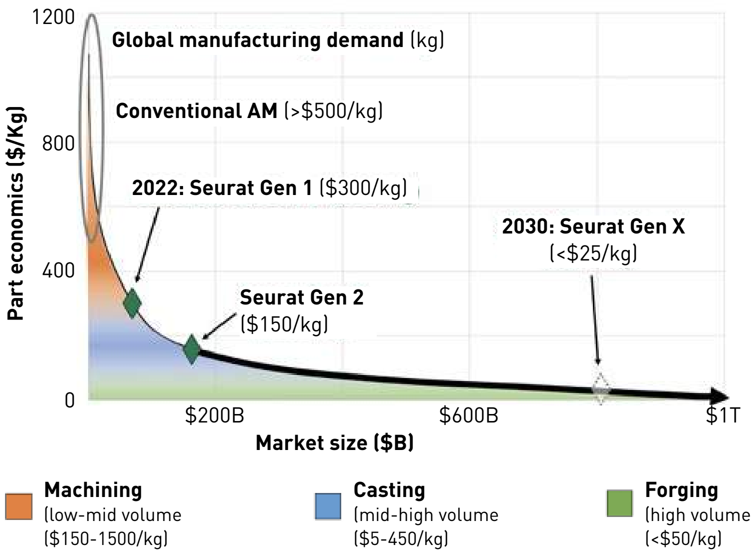

Fig. 6 Scaling the metal AM process (especially for PBF-LB) is required to harvest economies of scale and lower the cost curve. Area Printing aims to provide part economics comparable to castings with our Gen 1 system, and ultimately forging

> *"The $1 trillion metal part manufacturing market is heavily skewed to low-cost processes. Nearly 80% of the market is addressed with methods that manufacture parts for less than $150/kg."*

throughput and price targets for these systems are technologically and economically feasible due to the inherent scalability of the Seurat Printing System.

These throughput increases are achievable by upscaling the technology in the proof-of-concept machine that is in operation today. The key is to deliver more energy over larger areas (tiles), which demands more (or larger) laser modules and larger patterning areas. Additionally, the rate of delivery of each tile to the powder bed can be increased. Reaching 1,700 kg/h with Gen X will require laser technology advancements that make incredibly high energy delivery practical, both in terms of cost and physical size.

The $150/kg price target is also within reach with modest research and development. AM users are aware that the key elements of price for AM parts are machine operation (amortised machine cost and operational expenses), post-processing, and materials. Higher throughputs will decrease the machine operation component. Part fidelity (resolution, dimensional accuracy, and surface finish) reduces the post-processing cost. For the material cost, our analysis shows that as the consumption rate grows, the price per ton will decrease significantly. To achieve the $25/kg part-cost target, advancements will be needed in the powder production supply chain.

Throughput and economics

With the targeted performance numbers stated in the technology roadmap, how does Area Printing stack up against traditional manufacturing processes and conventional Additive Manufacturing technologies?

Economics

The $1 trillion metal part manufacturing market is heavily skewed to low-cost processes. Nearly 80% of the market is addressed with methods that manufacture parts for less than $150/kg. Clearly, as parts get more economical, the market potential increases. Equally obvious is that today's Additive Manufacturing processes are limited to a narrow sliver of the market, with output costs starting at $500/kg.

With the release of the Gen 1 platform, a $300/kg output cost positions Area Printing in the transition zone between machining and casting (Fig. 6). When Gen 2 is operational, the forecast $150/kg price will make it an economical competitor for castings. That opens the door to nearly 20% of the metal manufacturing market. And in less than a decade, Gen X (with an output cost of < $25/kg) has the potential to make AM an economical competitor to 80% of the total market.

Throughput

Conventional Additive Manufacturing processes trade resolution for throughput. Area Printing breaks that paradigm. With the release of Gen 1 and Gen 2 machines, Seurat will have a trajectory that isn't only off the curve; it plots a new course. The scalability of Area Printing allows throughput to increase as resolution improves (Fig. 7).

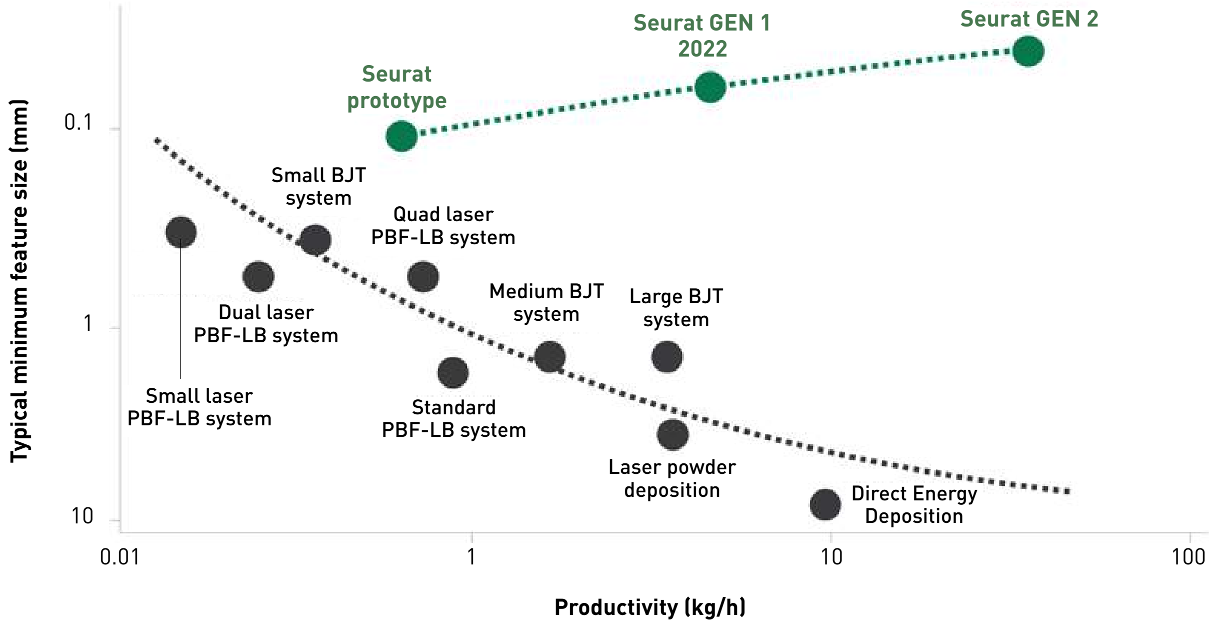

Fig. 7 Decoupling speed and resolution enables Area Printing to scale and enter uncharted territory and thus, entertain applications that haven't historically been approachable by metal AM. Every machine generation will be 10 x faster than the previous

Output: quality and materials

A fast and affordable manufacturing process is meaningless when speed and affordability means sacrificing quality or providing materials that do not meet an application's needs. Testing output from the proof-of-concept machine has shown that Area Printing offers high densities, high-quality surfaces, and material properties that exceed ASTM standards. Sample parts from the proof-of-concept machine achieved image resolutions of 6 to 10 µm (XY), 25 µm (Z), surface roughness of 2 µm, and showed excellent material properties (Table 2).

Any meltable material is a candidate for Area Printing. However, Seurat's focus is presently on metals, and initially specifically on steel and Inconel alloys. These were selected due to being non-reactive, minimising powder handling safety and regulations when storing and processing tons of the alloy. These alloys are also thermodynamically challenging for all metal AM processes. Overcoming these challenges allowed us to garner insights that will benefit the Area Printing of other alloys.

Compared to the current range of laser-based AM machines on the market, Area Printing provides distinct benefits when building challenging or 'unweldable' alloys. These advantages arise from the control and influence Seurat has over energy delivery during the build process. Another example is grayscale patterning, which allows precise control of both heating and cooling rates to overcome problems resulting from distortion, grain orientation, and other issues that impede the AM of desirable alloys.

	Yield strength (MPa)	Ultimate Tensile Strength (MPa)	Ductility (%)
Area Printing	288	627	59
ASTM standard	205	515	30

Table 2 Mechanical properties of 316L from Area Printing versus the ASTM standard

Go-to-market through Additive Manufacturing depots

Seurat has made a deliberate decision to offer manufacturing services rather than selling machines. The goal is to be a global manufacturing leader, establishing Additive Manufacturing depots around the world to manufacture parts locally and decentralise global manufacturing. The key factor for this plan is the need to characterise, quantify, control and qualify metal AM processes. Providing that expertise, Seurat accelerates the path to adoption for each part and

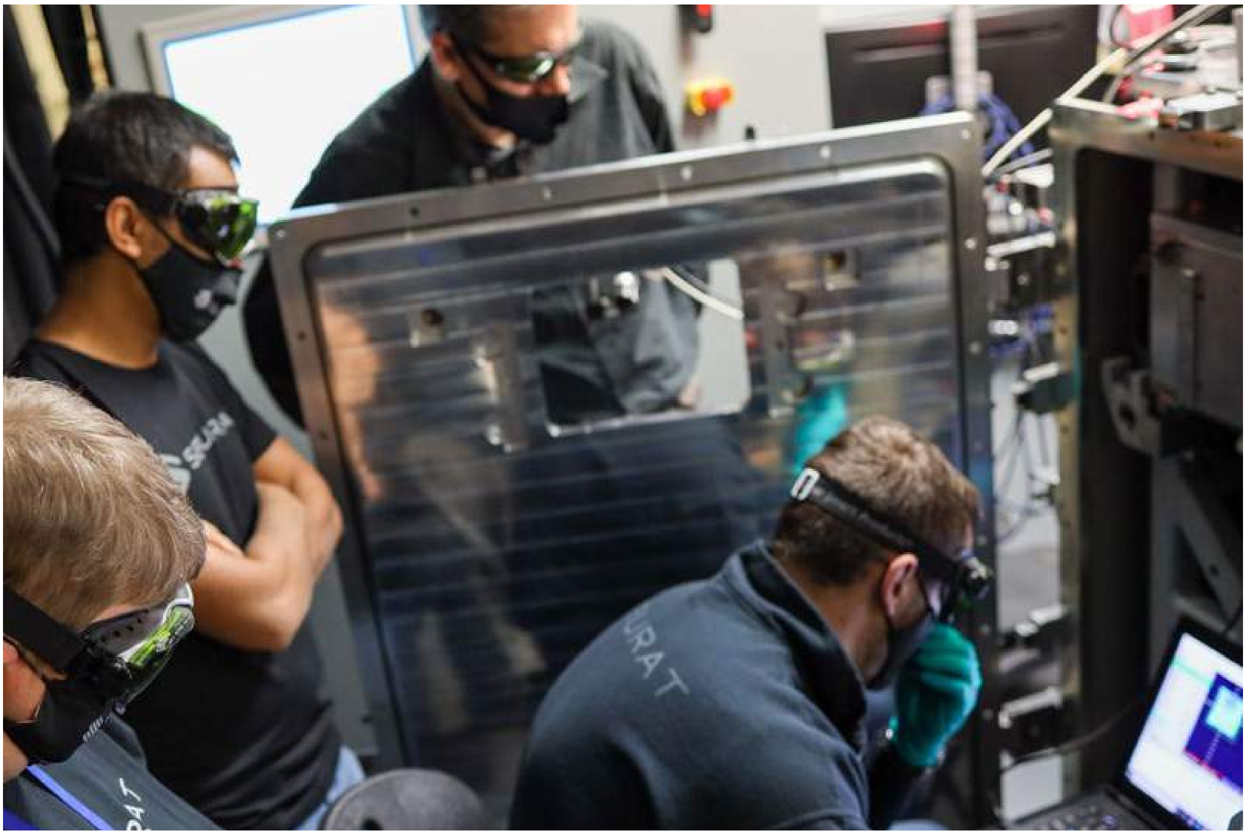

Fig. 8 Engineers from Seurat's Process, Mechanical, and Optics team collaboratively working on improvements to Seurat's beta Additive Manufacturing machine

every application. Shown in Fig. 9 is an injection mould tool produced by Seurat for United Aircraft Technologies.

Central to this plan is the Area Printing Production (APP) Program. The APP Program consists of three phases: material validation; machine, process, and application validation; and production readiness. Progressing through each phase, Seurat works with the customer to achieve specified material properties; match application targets, such as part price; refine the process; and ultimately achieve reproducibility and repeatability needed to scale up for manufacturing in high volumes. Since the APP process is resource intensive, Seurat will be working with select customers targeting high-volume manufacturing. Ideally, the candidates will require the production of more than 200 metric tons per year of parts with Area Printing.

"Seurat Technologies is on a mission to expand the Additive Manufacturing market while transforming global manufacturing for people and our planet. Our contributions will be through Area Printing and sustainability practices."

Decarbonising manufacturing

Seurat Technologies is on a mission to expand the Additive Manufacturing market while transforming global manufacturing for people and our planet. Our contributions will be through Area Printing and sustainability practices. Manufacturing must evolve, starting with a new approach to the tenuous global supply chain. Manufacturing must be brought back to sit alongside operations that consume the product output. By opening the door to more of the metal manufacturing market, Area Printing contributes to this evolution via a distributed network of AM depots.

Fig. 9 Left; Area Printing in progress to form one of the steel core pins for an injection mould tool that will be used to manufacture brackets for aerospace and defence customer United Aircraft Technologies. Centre; Eight core pins (four in the front, four in the back) with tensile bars and test cubes also on the build plate. Right; the finished part, a single core pin, built in 316L stainless steel

"Manufacturing must be brought back to sit alongside operations that consume the product output. By opening the door to more of the metal manufacturing market, Area Printing contributes to this evolution via a distributed network of AM depots."

Carbon-free production is critical in the effort to usher in the next generation of manufacturing. Seurat has a two-fold approach to sustainability. First, Area Printing reduces CO_2 emissions by displacing carbon-emitting manufacturing processes. Second, Seurat's production facilities will be entirely powered by renewable energy as of spring 2022. With the energy-dense process and the planned output tonnage, this has a marked effect on CO_2 emissions, unlike the minimal impact if renewables were used on AM machines for prototyping and low-volume production.

None of this would be possible when chasing incremental gains. Instead, Seurat is breaking barriers by decoupling throughput and resolution. Area Printing is an extremely scalable technology which will make metal Additive Manufacturing a fast and affordable option to deliver the consistent quality demanded by high-volume production.

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What does a decades old metal powder titan bring to Additive Manufacturing? In conversation with Höganäs AB

The metal Additive Manufacturing landscape is filled with ambitious, well-funded startups, all promising a wealth of materials innovation and ambitious value propositions. In contrast to these newcomers, Höganäs AB has been a powerful force in the metal powder market for near eighty years, producing half a million tonnes of metal powder annually. Is there a role for such a titan of Powder Metallurgy in the brave new world of AM? Emily-Jo Hopson-VandenBos spoke to Kennet Almkvist, president, Höganäs Customization Technologies, about what the company brings to the table.

To the wider world of metal powders, Sweden's Höganäs AB needs little introduction. For newcomers to the world of metal Additive Manufacturing who are unfamiliar with the landscape of metal powder production, however, perhaps some introduction is necessary. Founded in 1797 as a coal mining company in a small Swedish fishing town bearing the same name, Höganäs established its first iron powder production plant to serve the post-war industrial market of 1946 and, in the seventy-six years since, has gone on to become a world market leader for iron and other metal powders, with an annual capacity of 500,000 tonnes.

As of 2022, the company serves 3,000 customers in seventy-five countries and operates sales offices or plants in sixteen, from which it supplies a range of more than 3,500 products, most tailored to its customers' specific needs. It holds around 800 patents, employs 2,400 staff, and in 2021 reported a full-year turnover of 10,520 MSEK (approx. $1 billion). No exaggeration is necessary: Höganäs is a metal powder titan.

Of course, not all 500,000 tonnes of Höganäs's capacity is produced for press and sinter Powder Metallurgy (PM). According to the Metal Powder Industries Federation (MPIF), annual worldwide metal powder production exceeds 635,000 tonnes [1] and, based on the latest industry figures published by the European Powder Metallurgy Association (EPMA) and MPIF, press and sinter PM had an annual powder consumption volume of about 450,000 tonnes in 2020 in North America and Europe combined [2, 3]. Höganäs's markets include the 'other' world of metal powder not covered by this magazine's remit, such as brazing, soil/groundwater remediation, surface coating, water treatment, and other industries,

Fig. 1 Höganäs AB's headquarters in Höganäs, Sweden

where quality and performance are no less important, but the technology is very different in its markets, design potential and speed of production. Are your morning cornflakes 'fortified with iron'? If so, there's a good chance you're eating Höganäs iron powders. The range of applications for metal powders is vast and we cannot cover it entirely here, but, as an indication of the range of markets served by Höganäs, this should serve to illustrate the company's versatility, flexibility, and deep understanding of metal powder in all its forms.

Just how important are metal powders to AM?

Why should a reader of *Metal AM* magazine care about metal powders? Simply put, without high-quality metal powder (and with the exception of a very few wire-based, or solid- or liquid-state technologies), there is no metal Additive Manufacturing. And not just in those technologies which begin with a powder bed (Powder Bed Fusion [PBF], Binder Jetting [BJT]), or in which powder is jetted at high velocities onto a substrate (as in powder-based Directed Energy Deposition [DED]); even those Material Extrusion (MEX)-based technologies which use fused filaments or rods as their feedstock, or Vat Photopolymerisation (VPP) technologies that spread a slurry of metal paste across a build plate, begin with metal powder. It is vital for the metal AM industry that the powders it uses are high quality, standardised, and that metal powder producers have the ability to scale production beyond the small batches which have served much of the industry to date.

Capitalising on a new metal powder market

For metal powder producers, the metal Additive Manufacturing market offers a very attractive proposition. While powder volumes for press and sinter PM have fallen in recent years for a variety of reasons – chief among them a reduction in PM part weight in the automotive industry, with smaller, more efficient internal combustions engines, and a growing electric vehicle sector – the AM market continues to be forecast massive growth; a recent prediction has the total AM market reaching a value of $51 billion by 2030 [4]. Almost every major existing metal powder producer has either already entered, or made plans to enter, the AM powder market.

Höganäs made its first entry into metal AM in 2012, when it began exploring the potential in leveraging the company's knowledge of metal powders and sintering in relation to metal Additive Manufacturing technologies. In 2017, it purchased Metasphere Technology, a developer of plasma atomisation technologies for carbides and ceramics. The same year, the company launched Digital Metal's binder jet AM machines onto the market. In 2018, it announced the acquisition of H.C. Starck's Surface Technology, Advanced Ceramic & Metal Powders (STC); Fredrik Emilson, Höganäs's group president and CEO, stated that the acquisition would offer the group access to new markets and product groups within surface coating and Additive Manufacturing, and enable "the building of another strong segment in Höganäs's business, next to metal powder for pressed and sintered components."

Also in 2018, the company announced the formation of a new product area to meet growing market demand within Additive Manufacturing and Metal Injection Moulding (MIM). The new venture, Customization Technologies (Fig. 2), is now part of Höganäs's Industrial business area and covers the entire value chain for AM and MIM, from application development and technology support to market development and global sales. Soon after, it expanded its Johnstown facility in Pennsylvania, USA, for the production of metal powders for Additive Manufacturing and other technologies, and began constructing a new atomising unit at its facility in Laufenberg, Germany, for the production of high-purity metal powders for AM, sold globally under the trademark Amperprint®.

This new Vacuum Induction Gas Atomiser (VIGA) unit went into operation in 2020 and was added to the already present fleet of the existing three VIGA units. At the time, the company stated that the VIGA launch served as a blueprint for further planned conversion and expansion measures in Laufenburg. The plant was certified to ISO 9100 in June 2021, and the Johnstown facility expanded its capacity for high-alloy products in August 2021 with the completion of a fine powder atomisation building. This is to name just some items from a larger list of Höganäs's activities in metal AM in the decade since 2012; clearly, the company has every intention to claim its place as a giant in the comparatively new realm of metal powders for AM.

> *"It is vital for the metal AM industry that the powders it uses are high-quality, standardised, and that metal powder producers have the ability to scale production beyond the small batches which have served much of the industry to date."*

Fig. 2 The Höganäs Customization Technologies team attending a trade show. From left to right: Denis Oshchepkov, Deniz Yigit, Hervé Rousseau, Ralf Carlström, Kennet Almkvist, Michael Hinz

As is the case with any new field, new metal powder producers hoping to specialise in the production of powders for AM have emerged along-side established giants like Höganäs. The industry news circuit has seen regular announcements regarding research spin-outs, expensive new facilities, atomiser commissions, and, in general, the establishment of large metal powder production plants in anticipation of the coming boom in demand for AM powders. Competition to control the metal powder market may be the hottest it has been in decades.

I spoke to Kennet Almkvist, president of Customization Technologies at Höganäs, about the choice to expand into AM, what a decades old metal powder giant brings to this competitive field, and what he and the company believe lies ahead for Additive Manufacturing and metal powder production.

Why AM?

Höganäs' background in Powder Metallurgy has been to supply powders for press and sinter PM, an industry which is currently seeing conventional part volumes fall as a result of the decline of the internal combustion engine (ICE) in automotive, previously the biggest consumer of PM parts by weight globally. Many suppliers and service providers across the PM supply chain are, as a result, seeking to diversify their portfolios away from automotive and, in some cases, away from press and sinter PM altogether. To what extent have the challenges ahead for press and sinter PM part volumes played into Höganäs's decision to pursue the AM market more actively? According to Almkvist, one need only look to the company's history to see that its move into AM has little to do with a fall in PM order volumes, but is simply in line with its corporate philosophy – to identify and pursue new technologies and markets as they arise.

"Höganäs has lived through multiple disruptive business changes for its more than 200 years," he stated. "Our continuous business success is based on our long-term vision and the very forward thinking of our great people. Höganäs's company culture is all about our willingness to question the status quo by asking, 'so, what did you do today to change tomorrow?' This company culture, paired with our in-depth industrial experience as well as financially strong background, gives us the opportunity to undergo certain transformations once or twice a century."

"This situation is no different," he continued. "AM was identified as one of the future growth legs of the company well before the electrification wave began and while PM demands were still rising. Resources

Fig. 3 Kennet Almkvist, senior vice president commercial at Höganäs and president of Customization Technologies

were allocated, products developed, and acquisitions completed even while ICE engine demands were still increasing. It is true that we expect all growth areas in the organisation to rise, so our long-term vision and strategy is working out as we had envisioned."

So, while many companies are rushing to replace the income lost from a declining market for press and sinter PM parts (and thus powders), Höganäs's decision to take a slice of the AM pie goes back much further; rather than being based on a forecast slowdown in its traditional markets, it is based on what Höganäs believes is the inherent value proposition of AM, not as a replacement market, but as a high-value addition.

"We form our company strategy based on what we, as Höganäs, want to be and what role we feel we should play in the market, looking ahead to a horizon ten, twenty and fifty-plus years from now. We do so while well composed, evaluating facts and projections, typically many years before we have seen any indications of underlying weakness in any other core markets." As an example, Almkvist pointed to the company's soft magnetic products for e-motor applications, which entered development in the 1980s – long before the electrification of the automotive industry began. "Our assessment of the value proposition of AM is certainly appealing," he added, "and we aim not only to cut a slice of the pie for ourselves, but to actively assist in growing that pie for all market players, just as we do in the PM market."

Indeed, it's impossible to ignore the value proposition AM might offer to material producers if industry forecasts are correct. Whether they are accurate, and when the demand for metal powders for AM will be large enough to support the capacity for AM powder production globally, is among the most discussed topics on the show floor of any industry event, and the current overcapacity for metal powders has no doubt given some would-be powder producers pause about joining an already crowded market segment. I asked Almkvist how confident Höganäs is in the pace of AM's industrialisation and the corresponding growth in demand for AM metal powder at high volumes; as a huge company, for whom the phrase 'high volumes of metal powder' must have a different definition than it does for many smaller powder producers, when does a company like Höganäs expect AM market demand to support powder producers of its size and volume capacity?

"Höganäs is the market leader for metal powders, producing 500,000 tonnes per year, and therefore 'volume' – or, better, 'scale' – has a very specific meaning for us," he explained. In terms of the potential for growth in industrial demand for AM metal powders, he stated, "AM in industrial use has developed within the last decade in an impressive way. Beginning as an experimental manufacturing method for early adopters, it has found application in almost all industry segments worldwide. Maybe someone's expectations were even more demanding regarding the technological breakthrough, but enabling wide adoption, successful qualification and industrialisation takes time. We believe and foresee a double-digit growth for the market volume, but this is not just driven by our manufacturing capacities. It goes hand-in-hand with the success of our customers – technically and commercially. We have a joint responsibility to enable and support especially non-AM experienced tier-1s/OEMs for growing the entire ecosystem, rather than competing against single market shares."

What does Höganäs bring to the table?

"We do not see Höganäs as just 'old'," Almkvist explained, when asked what it is about Höganäs that sets it apart from its younger competitors. "We see us as a company which has lived through multiple disruptive business changes for its more than 200 years, driven by our responsibility to our employees and the community we are living in. Over the centuries, we have formed our DNA, which is all about transformation, invention, collaboration, scale and joined success from an entire industry perspective. One of our aims for AM is to address our evolutional deep expertise in metal powders and its wide applications within industry, gained on all continents across decades of experience. Especially the important knowledge which we have learned by being the top tier and large-scale supplier for the PM automotive industry (Fig. 4), which will help AM and its users to industrialise quicker."

This is key. As a company, Höganäs has experienced the industrialisation of a new metal powder-based production technology before, from its early rise to the present day, most importantly as one of the first suppliers to the press and sinter PM industry. For decades, Höganäs has supported PM part producers as they supplied the ever-changing and evolving automotive industry, from the peak of PM part consumption to its current challenges. "There is no other company worldwide who is producing, handling and bringing more metal powders into industrial use than we do," stated Almkvist. "This is the foundation of our strength and will be the source of our reliable joint success in metal AM."

Of course, it's been quite some time since the PM industry could be described as 'rapidly changing' or 'emerging', and the modern Höganäs is exponentially larger and more complex than the Höganäs that supported PM part manufacturers in their early days. When competing against agile startups, still establishing their company structure, do huge companies like Höganäs still have the speed and agility to respond to a rapidly changing, emerging market like this one? According to Almkvist, "Höganäs is actually more in the 'Goldilocks zone' for company size, in that we are large enough that we have substantial operations and resources all across the globe, but small enough that it is possible and very common to know each other. It is ideal in this way, as you have camaraderie and comfort no matter where you sit in the organisation, but still feel that you have substantial resources supporting you."

"In addition, the AM group in particular is a highly specialised global team, which can independently act as a centralised business unit under the umbrella of the Product Area Customization Technologies within the Höganäs Group, reporting directly to the CEO," he added. "As a result, we can offer coordinated support even for our multinational customers, by almost 'mirroring' the customer structure and setting up interfaces wherever on the planet they may add value."

Fig. 4 Höganäs is a leading supplier of iron powders to the global Powder Metallurgy industry. Its powders are used to produce high-performance powertrain components such as these fracture-split connecting rods, main bearing caps and camshaft/crankshaft sprockets (Courtesy Höganäs AB)

Fig. 5 One of Höganäs's large-scale metal powder atomisation facilities for AM

A key tenet of Höganäs's business philosophy is 'Ease of Access,' and the company has stated its ambition to become a one-stop source for any metal powder need in future. I asked Almkvist how Höganäs plans to service this statement. The world of metal powders is vast and the needs of metal powder-based manufacturing continually changing and developing as time passes and industries evolve. Does the company plan to build its own expertise to the extent that it can produce any metal powder, or will it be necessary to acquire other companies, or incorporate powder reselling into its business model?

"Because every customer in the world should have easy accessibility to a broad product portfolio, we are continuously leveraging our regional and operational footprint, as well as looking into new atomisation technologies," Almkvist stated. "This is also the reason why Höganäs has a variety of powder atomisation technologies in-house, such as Inert Gas Atomisation (IGA), Vacuum Inert Gas Atomisation (VIGA), Plasma Atomisation (PA) and Water Atomisation (WA)." As one example of the company's drive to develop its own alloys to suit every industry need, he raised the company's high-strength aluminium alloy for AM, developed in-house and set for launch this year. "Development [of this alloy] started more than two years ago, when we even did not have Al-base materials within our standard AM portfolio," he explained. "This shows our engagement and interest in adjacent material classes, which were then integrated into our deep solution-based offerings."

Almkvist further noted that Höganäs's strong collaborations and partnerships with industry, driven by extensive engagement in scientific and industrial networks, is a great support for its short time-to-market strategy for new products.

From 'conventional' powders to highly specialised materials

For many material producers turning their attention to the AM powder market, something of a learning curve is inherent, as a new form of powder producing technology – namely gas atomisation – must be understood and implemented before any financial gains can be made. Even prior to its entry into the world of AM in 2012, however, Höganäs had already amassed several decades of experience in gas atomisation. "Höganäs has produced and delivered large volumes of gas atomised powders out of our plant in Ath, Belgium, into various markets for more than forty years," stated Almkvist. "At that facility, we operate an entire fleet of gas atomisers." At the facility, Höganäs produces cost-efficient AM powders, such as low-alloy steels suitable for the automotive industry.

Expanding its gas atomisation expertise was one of the driving factors for the company's acquisition of H.C. Starck's STC business. At the time of the acquisition, STC employed close to 400 people, mainly in Germany, where it had two production units serving a primarily European customer base. STC brought Höganäs access to new markets and product groups within the premium segment for surface coating and Additive Manufacturing, but, perhaps more importantly, the acquisition brought with it expertise in even more specialised metal powder atomisation technology.

"After the acquisition of H.C. Starck's division of surface technology in 2018, we were able to expand our powder production capabilities towards Vacuum Inert Gas Atomisation," explained Almkvist. "This benefited our in-depth operational experience while intensifying our engagement within the AM powder production arena."

The company now operates a fleet of VIGA systems in Laufenberg, Germany (Fig. 6). "Here, we produce our highest quality AM powder grades for various industry segments, as well as for the most demanding applications," said Almkvist. "Germany was from early on and still is an important and internationally recognised AM technology hub, which has helped us form strong partnerships and grow the AM business. We invested in a new state-of-the-art VIGA atomiser in 2020 and have already ordered an additional larger unit (operational soon) for our German production centre."

Outside of Europe, the company benefits from a global supply network for gas atomised powders, which has enabled it to form further strong business relationships in APAC and the Americas. The next step in building its atomised powder capacity, according to Almkvist, will be "leveraging additional capabilities as we do in Johnstown [Pennsylvania, USA], where we are in the final steps of commissioning our Fine Powder Atomisation (FPA) plant for addressing tech areas such as Binder Jetting and Metal Injection Moulding."

Fig. 6 A VIGA system installed at Höganäs's plant in Laufenberg, Germany

"Our Fine Powder Plant in Johnstown, US, is not just an addition of 'another' water atomiser for us, it is a highly engineered production process for optimised and tailored powder solutions for Binder Jetting and Metal Injection Moulding."

FPA is a water atomisation technology which can be advantageous in the production of metal powders for binder jet AM and MIM, which do not always require gas atomised powders. As a relative, if very promising, newcomer to the AM technology marketplace, BJT is a technology just starting to gain market penetration with the material offering currently available. I asked Almkvist whether he believed the cost benefits of adding water atomisation into this mix outweighed the added complexity of introducing yet another powder offering into the marketplace?

"We believe that it is the opposite of adding complexity," he explained. "By 'adding' valuable alternatives, we are broadening the solution toolkit for the industry. Any new technology competes in the early stages against established technologies; this could be based on performance, usability as well as the customer's total cost solution. Our Fine Powder Plant in Johnstown, US, is not just an addition of 'another' water atomiser for us, it is a highly engineered production process for optimised and tailored powder solutions for Binder Jetting and Metal Injection Moulding."

"Höganäs has a long-term expertise in the PM industry and in-depth experience in sinter-based technologies using water atomised powders," he added. "We are leveraging this key knowledge towards binder jet technology."

Fig. 7 Höganäs's facility in Johnstown, Pennsylvania, USA

The AM powder portfolio

Already, Höganäs offers a considerable range of metal powders for AM. To list every powder in Höganäs's AM materials portfolio would turn this article into a catalogue, but, to illustrate the progress Höganäs has already made toward a diverse offering of advanced AM products, some of the materials available are listed below.

Nickel-base alloys
Some of the more popular nickel-base superalloys produced by Höganäs are Haynes® 282® and Amperprint® alloys 625, 718 and 939. These alloys are used for a wide range of demanding Additive Manufacturing applications, made possible by their high strength at high temperatures and good corrosion resistance properties in extreme environments. According to Höganäs, aircraft gas turbines, steam turbine power plants and nuclear power systems are just a few of the demanding applications where nickel alloys are typically used. Both of its AM metal powder series and Amperprint atomised metal powders have been engineered for the specific requirements of AM.

Cobalt-base alloys
Höganäs's Amperprint cobalt-chrome alloys can be applied in biomedical applications, as well as being suitable for demanding high-temperature applications such as aero engines. These alloys are characterised by exceptional mechanical properties, as well as high corrosion and temperature resistance.

Steel alloys
Höganäs describes steels as the 'true workhorse' of the metal AM industry – as, indeed, they are in most industries. The good availability and the cost effectiveness of iron makes steel and steel alloys a popular choice in automotive for the production of construction and wear-resistant components. Tool steels, which combine high hardness, wear and temperature resistance are used to produce moulds, stamps and cutting tools across a range of industries. Austenitic and duplex stainless steels have found many applications in the oil and gas industry. Several grades of precipitation hardening steels are developed and used in the aerospace industry. Höganäs offers a wide range of steel-based metal powders, including in its AM and Amperprint series, covering a wide range of industrial demands in terms of cost, properties and standardisation levels, including stainless steels, construction steels and tool steels.

Titanium, aluminium & copper
A range of products based on these elements are just being introduced to the company's portfolio, and market introduction began in March 2022.

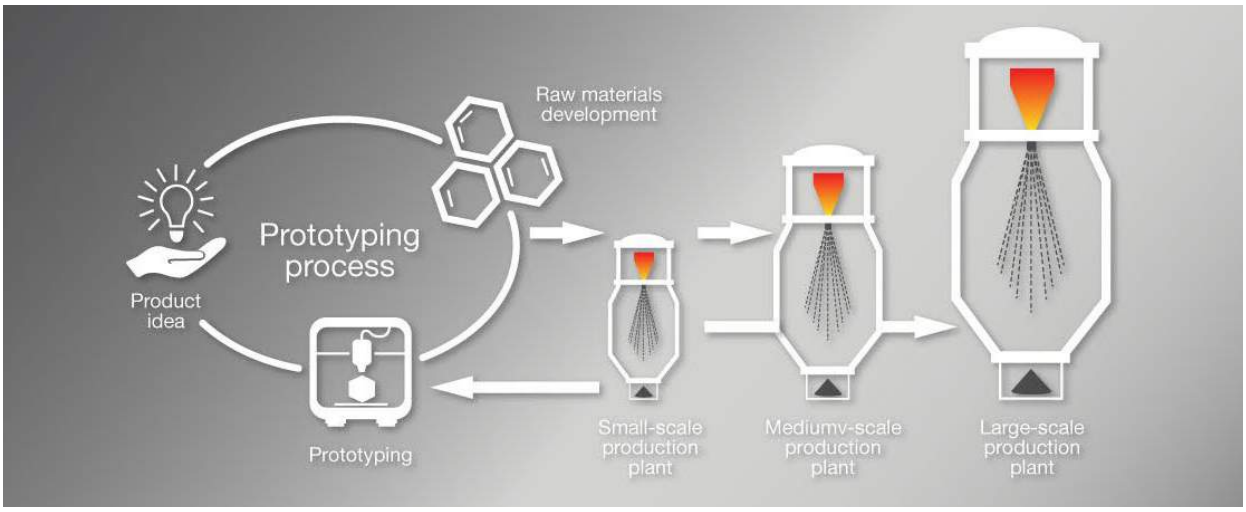

Fig. 8 Höganäs's ability to scale from small batch powder production to medium- or large-scale production enables it to help customers develop customised powders for their products from initial idea to series production

Customer-specific material development

Drawing on its decades of expertise in the development of metal powders to support the needs of real industrial production, Höganäs offers customer-specific material development to its metal Additive Manufacturing customers. Based on collaboration and discussion with customers, the company is able to tailor powder particle size distribution (PSD), morphology and chemical composition to its customers' needs, produce small-scale batches for research, development and prototyping using its small-scale production plant, then ramp up production to its mid- and large-scale atomisers when the customer is ready to move into medium- or industrial-scale production (Fig. 8).

Because the company's plants are identical and highly standardised in terms of technology, Höganäs states that it is easy to ramp up production from small to medium to large scale as demand increases. This enables consistently high quality standards, identical morphology and consistent PSD in combination with fully optimised production processes, avoiding the bottlenecks that can challenge a new production process as it attempts to scale for volume. It also minimises the risk management for our customers using our products that are produced in interchangeable atomising units.

Quality, consistency and standardisation

A key area of development to enable the wider industrialisation of AM is the standardisation of materials and processes. For a new technology, this greatly enhances trust and confidence amongst end-users – perhaps most visibly in safety-critical, high-value industries such as aerospace and medical, but eventual standardisation will be required by all end-users; even luxury goods makers stand to lose money if a part fails. As a long-time supplier of metal powders to press and sinter part manufacturers for the automotive industry, Höganäs is no stranger to standardised, quality-controlled production, but how does the company guarantee consistency and standards in this new market? Is AM still something of a 'wild west' for manufacturing, or is it now well-controlled and understood?

"We follow strict manufacturing process protocols under our numerous certifications (various ISOs, AS9100, IATF, etc) and in conjunction with our established Höganäs quality management system worldwide," explained Almkvist. "Our decades-long experience in atomisation and the supply of our powders to various markets with application-critical performance requirements has enabled us to further develop streamlined and highly controlled processes for advanced, consistent and reliable metal powder solutions from batch-to-batch, month-to-month and year-after-year. This is absolutely key for us and our customer's success journey."

Regarding where the rest of the AM industry sits on its path to standardisation, he stated, "AM's industrialisation has developed impressively within the last decade, but [the level of standardisation] depends entirely on where a company is in its AM adoption cycle. Some users already have decades of experience with AM production and have found their sweet spot using AM, others are in a pseudo-industrialised stage, while others are really experimenting, learning on the fly, and, in some ways, they are a bit more 'wild west' as you described it."

"But this will definitely change over time," he added. "We all – as an AM community – learned within

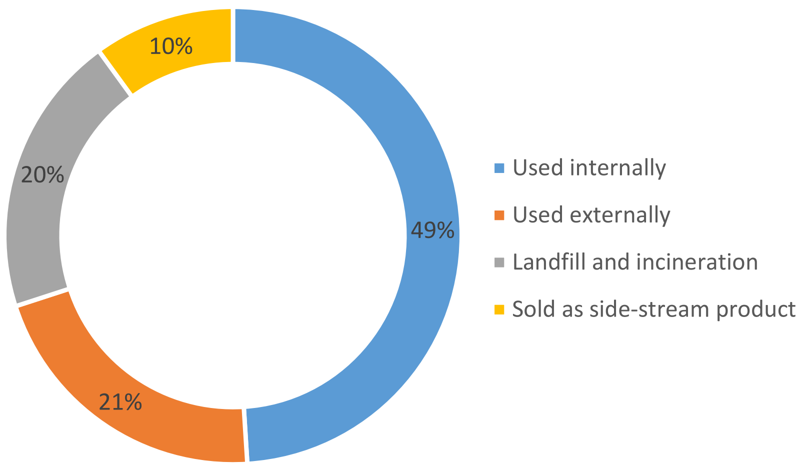

Fig. 9 In 2020, Höganäs diverted 80% of its process residuals from disposal, with the remaining 20% sent to landfill or incineration

recent years that this technology has to adapt in evolutional steps rather than looking for quick, disruptive revolution in all industry segments. Our combined focus on qualification and industrialisation for targeting a technological breakthrough by enabling the targeting of industrial segments is key for growing the pie."

Sustainability and 'making more with less'

For many years, a focus of Höganäs has been the sustainability of its business, processes, materials and wider industry. Since 2010, the company has achieved an 8.1% energy reduction and reports that it has saved 30,400 tonnes of CO_2 emissions by using electricity from renewable sources. Further, 80% of its process residuals are diverted from disposal (Fig. 9). A key phrase which appears again and again across company literature and presentations is at the core of its philosophy as a sustainability-minded materials producer: "Inspire industry to make more with less."

As a relatively new manufacturing technology, developed in an environmentally conscious era and capable of producing whole parts with the very minimum of material waste, AM has the opportunity to approach its entire value chain with sustainability in mind. A number of organisations and networks seek to ensure that the industry takes full advantage of this opportunity, perhaps chief among them the Additive Manufacturing Green Trade Alliance (AMGTA), a non-commercial, unaffiliated organisation established by Sintavia in 2019 with the aim of promoting the environmental benefits of AM over traditional methods of manufacturing. Höganäs joined the AMGTA early this year as a founding member, as well as establishing a partnership with Sweden's Piab AB which aims to advance automated powder management methods for binder jet and PBF-LB Additive Manufacturing, with the goal to increase the sustainability and efficiency of the processes.

Discussing Höganäs's perspective on sustainability in AM and how the group is dealing with this facet of its metal powder production, and its day-to-day running, Almkvist stated, "Sustainability is and has always been a crucial part of our company. It is our sustainable business practices, always evaluating applications and use cases for secondary raw material streams and increasing material efficiency overall, which allowed Höganäs to develop 'metal powder solutions that help industries make more with less.' Therefore, we are already recognised as frontrunners in sustainability within the metal powder industry, which we intend to maintain and even further enhance."

"We are also more broadly publishing our activities within the Höganäs annual sustainability report and have employed a full-time sustainability team for many years," he added. "Höganäs has also committed to and joined the 'Science Based Targets initiative' for driving the corporate climate roadmap towards zero impact by 2045 at the latest. We have even investigated accelerated scenarios for becoming net-zero sooner in conjunction with all our related downstream and upstream processes worldwide."

The company's primary metal AM powder production centre in Laufenberg is already fully hydroelectric, Almkvist explained, powered by the Rhine river. Its Ath plant draws power from a solar panel park (Fig. 11). In addition, all of the company's powder manufacturing processes are already carbon neutral or close to neutral. "We are currently working on all other indirect emissions occurring from sources beyond our control, which are based on sourced materials and consumables."

"All this contributes to our sustainable AM activities, offerings and services as well, where we define our efforts in relation to a key tenet of our AM value proposition – 'every particle counts.' Here, we are actively developing material handling solutions to help our customers industrialise, which is a crucial step for AM to reach mass adoption," he continued. "We are leveraging our long-term expertise handling large-volume markets such as PM. This gives us and our customer a glimpse into where the AM industry has to move in the following years. For example: using large-scale packaging solutions rather than single polymer bottles, in conjunction with automated powder handling equipment. We are also working with some customers already on recycling concepts to not only reduce cost, but reduce the environmental impact of metal AM powders by enabling secondary raw material streams."

Supporting the development of AM to ensure market growth

As a leading producer of metal powders for press and sinter PM, Höganäs has a long history in researching and developing new applications for the technology and has been a major champion of the process in high-value, high-volume sectors like automotive. On its Powder Technologies homepage, the company states, "Our vision is to make metal powder technology the first choice by helping customers and end-users to utilise the inherent 'power' of metal powders." These efforts to increase PM's visibility to automotive part makers and end-users are visible across Höganäs's online network of resources. One such example is the company's AutoExplorer, which highlights efficiency-increasing applications for press and sinter PM in gasoline/diesel cars. This interactive tool allows users to view the components of a modern vehicle, piece by piece, identifying those for which press and sinter PM is ideally suited (refer back to Fig. 4 for example parts from AutoExplorer). Through its Customer Development Centre, Höganäs provides a platform for cross-functional work with different companies and competencies to develop applications that work across all steps of the PM value chain, from idea to finished product.

Fig. 10 Höganäs's metal powder production facility in Ath, Belgium

Fig. 11 The solar panel park at Ath

Based on this well-established approach to the market, heavily promoting the technologies for which it provides the materials, Höganäs would seem to be an ideal materials partner for a burgeoning new field such as metal AM. So how involved is Höganäs in developing new applications for AM?

"For PM, it is a necessity for us to develop new applications together with our customers to be able to secure, as well as further address, new markets for press and sinter technology for growing the business space," Almkvist stated. "In AM, we are following a similar approach and working internally as well as externally together with our customers. These activities are enabled by collaboration or putting a development agreement in place, where we support customers in selected industry segments such as aerospace, automotive, dental, energy, tooling and others. Since AM is a relatively young manufacturing technology, development is not only based on new applications; some developments are based on industrialised powder handling solutions, sustainable material circularity or new AM technologies."

As with any new technology, a large part of the challenge of industrialisation is in education. Much has been said of the skills gap for AM, and, to date, the education system does not provide AM training on the scale necessary to support industry growth. As such, much of the responsibility to provide training in AM and its associated skills falls to companies along the value chain. So, how does Höganäs plan to support those customers who are new to AM and whose staff may not have much

"A wide and varied metal powder production ecosystem is of course of value, both in material options and scale, but this will not be a market where anyone with an atomiser will enjoy a nice slice of the pie..."

familiarity with metal powders, in understanding this new area?

"During the past years, Höganäs has developed competency and capability in all aspects of the AM value chain addressing the 'ease of use' principle, starting from requirement engineering/alloy development, through to optimised/sustainable production, through to application engineering/printing/post-processing and beyond," said Almkvist. "Our aim as top-of-the-mind solution provider is to enable the visions of our customers even if they do not have a printer. The scope of this may vary for each customer or application, and we will approach it similarly to how we did it in the PM world for decades. We will educate them on the process options and materials and offer the ability to produce proof of concept parts for test/qualification. We do not intend to become a parts producer, as we consider that the domain of our customer base, but we can support them in connecting with trusted manufacturing partners to produce parts in serial production using the powder-based AM solution they developed together with us."

Education plays a major role in industrialisation, as Höganäs has known for many years, as one of the key educators driving awareness of press and sinter PM and the vast potential of metal powder. Now, the company is expanding this focus on promotion through education to include AM and its end uses. In September, the company joined the Connactive project to help develop new automotive electric drive concepts based on the use of metal powders. Established in 2019, Connactive brings companies together with the goal of fostering innovation and is currently focused on the production of an enhanced-efficiency motor using AM-enabled technology and dedicated material solutions. As part of the project, Höganäs's metal powders were used in Connactive's Dual Drive System, a powersplit planetary gearset and matching RX II unit, in combination with a high-torque AX motor and highly integrated electronics. Leveraging the abilities of partner companies Dontyne Gears, Moteg and Vishay, the Dual Drive System was brought from blueprint to series production standard prototype within six months.

The long-term view on AM's metal powder marketplace

Twenty years ago, the number of metal powder producers in the world could have filled a page at most. Now, this is a rapidly swelling market with a number of new players emerging year by year with new claims as to their powder's quality, sustainability, and suitability for AM processing. As is common across the AM value chain, this is an attractive space for startups and a great deal have popped up over the past few years, as well as spin-outs from larger companies, universities and research organisations. Suddenly, the list of metal powder producers globally is quite long. So, where does Höganäs, one of few experienced elders in the marketplace, see this going? Is the inevitable conclusion market consolidation as the industry matures, or is a wide and varied metal powder production ecosystem of value to the industry?

"A wide and varied metal powder production ecosystem is of course of value, both in material options and scale, but this will not be a market where anyone with an atomiser will enjoy a nice slice of the pie," Almkvist explained. "We believe that in the coming years certainly some market consolidation will occur, but also, many of the smaller newcomers will struggle unless they are capable to present a truly differentiated product offering. At this stage, machine OEMs for the AM process themselves are still working on making more robust products in conjunction with addressing new materials, so in many cases the end-users are still very much trying to limit any variables within the entire process chain. As consequence, they tend to work with suppliers they know and trust who have a product that is qualified and has demonstrated proofed performance. We at Höganäs are investigating alternative/new powder manufacturing processes and are strategically down selecting potential candidates."

"It is not new that various metal powder manufacturing technologies with different TRL are known within the technical community," he added. "Some of the technology principles on offer were already scientifically investigated years ago but were either not ready for scale-up or certain product did not find the right fit-to-market."

Within the busy metal powder marketplace, another key issue is price. Currently, it would be fair to state that metal Additive Manufacturing has a reputation as an expensive manufacturing solution. Whether this reputation is entirely fair or not, it is partially down to material cost – highly specialised, gas

Fig. 12 One of Höganäs's Laufenberg VIGA systems in operation

atomised metal powders for AM cost significantly more than the metal powders used in press and sinter PM, and much more than many of the materials used in traditional, subtractive manufacturing technologies. As a result, many discussions around material development and metal powder production for the AM market focus on the need to reduce material costs – or adjust AM processes to enable the processing of cheaper materials – in order to make the AM business case viable for all part makers, not just those in extremely high-value industries such as aerospace and medical.

I asked Almkvist what Höganäs's long-term view is on pricing for AM powders. Will powder prices drop enough to tilt the scales toward viable business plans for part makers in the near future? Where can people in the planning stage of applications, which may be five years down the line, expect the pricing of atomised metal powders to be in 2027?

"This is not the first time that we've heard this question as a powder supplier," Almkvist stated. "Of course, it is true there are economies of scale to be realised, but that isn't the whole picture. A significant reduction in costs will not be achieved by volume increases alone; it will require deep investigation into what powder characteristics (chemistry, PSD, morphology, etc) are truly necessary to produce the desired product. This will require cooperation between powder producers, machine producers and the customers making the parts."

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"In the end, we have to find a way to grow the pie, rather than competing for single market shares, since AM is competing against other, well-established manufacturing process technologies."

In Almkvist's opinion, however, the role of material cost in holding back AM's industrialisation has been somewhat exaggerated. "Powder costs are only one (small) piece of the puzzle, as in PBF-LB, for example, the material costs can be ~10-20% on average of the total production cost," he stated. "The reason it gets so much attention is because it is a visible line item. Increasing the layer thickness or other methods to turn up productivity in the AM process or reduce downstream post-processing requirements would have a much larger and more immediate impact on total part cost than simply reducing the powder cost."

"As an exercise to illustrate this," he added, "look at one of your cost models for a programme five years out and bring the powder cost to $0. Is your problem entirely solved? Likely not."

Conclusion: growing the pie

Höganäs is a company that began at the explosion of industry and has ridden (and sometimes helped steer) the waves of industrial progress for two centuries. As metal AM continues to grow, this is a company which is sure to thrive along with it, while maintaining the traditional base that has given it one of the deepest wells of knowledge in the metal powder industry.

Much discussion of the advanced metal powder marketplace, by the nature of business, focuses on the rush for market shares; who will win the largest slice of the pie? In speaking to Almkvist, however, it is clear that this is not Höganäs's biggest concern – the company already produces 500,000 tonnes of metal powder a year, after all, and serves a large portion of the metal powder manufacturing world. Höganäs can afford to choose carefully what future it invests in, to the benefit of its business, its community, and the metal powder industry at large.

"We believe in and are fascinated by AM technology and wish to deeply express our willingness to support the AM industry with our decades of experience in metal powders," Almkvist concluded. "In the end, we have to find a way to grow the pie, rather than competing for single market shares, since AM is competing against other, well-established manufacturing process technologies."

The message is clear: why expend resources on the fight over slices of a small pie, when you can invest them to make the pie bigger? To mix our metaphors, a rising tide lifts all boats – and a larger pie feeds more mouths. Competition is inherent to business, but so too is collaboration inherent to progress, and to Höganäs, until metal AM is in a position for true industrialisation, progress must come first.

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Innovation to commercialisation: Atherton Bikes and the journey of an SME bringing AM production in house

Bringing Additive Manufacturing in house is a big step for any company, but when you are at the small end of the 'SME' spectrum, it can be an especially bold move. Robin Weston recently visited Atherton Bikes, based in rural west Wales, to see how this specialist bike producer is enjoying ramping up in-house production of its titanium and carbon fibre performance mountain bikes on a new, four-laser Powder Bed Fusion (PBF-LB) machine from Renishaw.

Metal Additive Manufacturing is expensive, demanding and out of reach of 'normal' companies. "What?! Now you tell me," I hear you cry. I speak as someone with over fifteen years of experience 'sweating the numbers' as a product manager in AM machines and it is often, although not always, the justification for the first machine's purchase that seems to cause the most pain. It gets easier to make the numbers work once multiple machines are installed. Better economies of scale, division of labour, more efficient utilisation, etc. Even then, there must be a compelling reason to invest, whether that's performance materials, complex geometries, part consolidation, customisation, or any combination of reasons to go down the AM route.

When Atherton first started using metal AM for its competition bikes, the project fell right into the AM 'Goldilocks zone'. The technical case was solid: titanium material – tick, demanding and unique geometry – tick, and customisation – tick.

In my previous article in the Autumn 2020 (Vol. 6 No. 3) issue of *Metal AM* magazine, we took a deep dive into Atherton's journey from a family of world-class, world cup-winning mountain bike riders to a company of ambitious bike manufacturers and adopters of new manufacturing technologies and approaches. However, at this point, the Atherton team didn't own an AM machine: components were supplied as part of a machine vendor project to demonstrate the viability and

Fig. 1 Rachel Atherton and her brothers Dan and Gee have dominated in the downhill mountain bike world since 2004 (Courtesy Atherton Bikes/Dan Griffiths)

Fig. 2 Will May-White, Lead Manufacturing Engineer at Atherton Bikes, with the company's RenAM 500Q PBF-LB machine from Renishaw (Courtesy Atherton Bikes/Dan Griffiths)

usefulness of metal AM in an open-access project, to showcase AM in performance sports equipment and, in so doing, attract others who could see parallels with their projects and businesses.

Atherton was working with its first fifty customers at the same time as honing the race team's prototypes, learnings from which fed directly and almost immediately into the production models.

After a recent visit to Atherton to get updated on how things are progressing, much has changed. The company now has its own metal AM machine on site and has recruited a team of engineers to develop and support its in-house manufacturing processes, all housed in a new (to Atherton) factory, just down the road from the Dyfi Bike Park. Coupled with this is a healthy order book and commercial bike supply is now well underway, with extremely positive bike industry reviews of the commercial machines coming in that further support the Atherton approach.

"The company now has its own metal AM machine on site and has recruited a team of engineers to develop and support its in-house manufacturing processes, all housed in a new (to Atherton) factory, just down the road from the Dyfi Bike Park."

Evaluating the options: subcontracting AM production versus bringing it in house

So, what are the advantages behind the major step of bringing AM part production capabilities in house, rather than developing a commercial supply partner to take over from a machine vendor? The latter option is the relatively low-risk approach, with smaller companies often initially working with machine vendors to develop some knowledge, before engaging with a commercial subcontractor, which then produces the matured component design to the exact customer specifications.

Whilst outsourcing is often the path of least resistance and, with the right supplier, a successful supply partnership suits many companies, it demands a detailed approach to capturing engineering data; there are potentially more variables in AM than other manufacturing processes, especially when configuring builds.

For efficiency, many subcontractors will want to fully populate each machine run, unless otherwise agreed. If your parts are nested with other components for other customers, any changes to how each build runs can impact part variability. Defining the exact processing conditions for your parts should therefore be part of your terms of supply, but you might expect to pay a little more to dictate such terms. It's not just the geometry that's important, but where the parts are placed, how the fusing energy is applied, how the support structures and part orientation affect the post-processing and final finishing of the components and, ultimately, the overall result. There is an increasing abundance of suppliers who provide AM manufacturing services. Many are well versed in the demands of high-quality production manufacturing and also run precision post-processing technologies to offer a complete service.

The alternative approach is to bring metal AM technology in house and much of the decision here depends on a company's appetite and ability to raise capital investment and to recruit and develop the skills required to become an AM manufacturing expert. Anyone who has researched the latest multi-beam, productive metal AM systems will know that the capital required runs well into seven figures, whether that's in dollars, euros or British pounds. There is also much to consider about the factory environment, skills and post-processing technologies required.

When I visited the Atherton factory, it had just installed its new metal AM machine. It's hard to overstate what a bold move this is for a young, dynamic and pioneering SME. Although I recognise that multi-laser metal AM machines are becoming the norm

Fig. 3 A build underway in the RenAM 500Q (Courtesy Atherton Bikes/Dan Griffiths)

Fig. 4 A build plate ready for removal (Courtesy Atherton Bikes/Gee Milner)

Fig. 5 Manual post-processing of the AM components (Courtesy Atherton Bikes/Gee Milner)

Fig. 6 A frameset read for final assembly (Courtesy Atherton Bikes/ Gee Milner)

Fig. 7 Bonding the AM components with carbon fibre tubes leverages best-practice from aerospace and motorsport (Courtesy Atherton Bikes/Gee Milner)

these days, it's only a few years since this advance in the technology actually emerged.

Getting to grips with optimising a machine's performance is not without its challenges. Hearing the Atherton engineers talking in detail about how they use 'swim lanes' to manage process emissions and the interactions between the multiple beams on the company's Renishaw RenAM 500Q machine, clearly shows that process knowledge is key to success. Having this capability in house means decisions about how parts are designed and nested are informed by an understanding of the manufacturing process that onlt grows over time.

Whilst I know one can achieve this in partnership with a component supply chain partner, it does reveal the additional dimensions that might not be apparent without direct experience of running an AM system. It is also clear that part production volume also helps populate builds more efficiently. Whilst is possible to produce a single frameset on in one machine cycle, something that takes around sixteen hours for a single frame, it turns out that because it's possible to produce approximately 1.3 framesets on a single substrate, the most efficient use of the machine is to make batches of component families. This also overcomes the other variable of inefficient laser use due to the differing heights of components. When producing a complete frameset in one build, the taller parts keep building after the shorter pieces are finished; while some AM machines can use all lasers on the remaining taller parts, this is potentially inefficient and risks differing thermal histories in the latter regions of the components, which may affect part variability and metallurgy.

The skills factor

From talking to the team, it's evident that skills play a crucial part in developing in-house capability. With Atherton, based out in the relative wilds of rural Wales, the question

Fig. 8 Final assembly of the bike to customer specification (Courtesy Atherton Bikes/Dan Griffiths)

of recruitment and attracting the right skills and capabilities was a concern. Passion is key and it's evident that the outdoor extreme sports environment plays a big part in attracting talent. When compared to alternative career paths in large corporate firms, working with the Atherton team is much more like working in F1, with the bonus chance for every staff member to throw themselves off a mountain top on one of the company's products, should the mood take them. I'm sure the HR department comes to work on Monday with some trepidation, though!

As anyone experienced in metal AM will also attest, passion is vital if a company is to meet the challenges of making successful AM parts. There are steep learning curves to climb and, particularly for the Atherton team, the challenge of fitting the Renishaw machine into a relatively modest (but admittedly rather cool) facility.

Preparing the environment for the machine included an appropriately specified environment for the AM machine and ancillaries. This includes environmental air handling equipment due to the small space available, storage for processing gas, changes to the floor to support the machine load, and providing suitable isolation from potential vibrations from passing trains on the nearby railway line. From selecting and defining a metal powder supply chain and ensuring the specifications are consistently achieved, to dealing with waste filters from the process gas, there is much to consider when running a metal AM machine in house.

"From selecting and defining a metal powder supply chain and ensuring the specifications are consistently achieved, to dealing with waste filters from the process gas, there is much to consider when running a metal AM machine in-house."

Fig. 9 The finished product (Courtesy Atherton Bikes/Lewis Bell)

Make or buy (innovate or die)

Is it worth the effort? Wouldn't it just be easier to send the geometry out to suppliers for the most competitive quote? True, it looks like it might be on paper, but that misses the point. When aiming for excellence, part of the process is to be empowered to explore the performance envelope of your production capabilities fully. If you subcontract, how do you know what you are getting is as good as it can be? Are there opportunities you could be missing to improve your product or innovate? Many bike manufacturers are commoditised, with only a few companies truly innovating. Many well-known brands are using the same supply chains and, whilst these companies can make capable advanced products by this route, the innovation pathway is thus limited for the most high-end products.

"Wouldn't it just be easier to send the geometry out to suppliers for the most competitive quote? True, it looks like it might be on paper, but that misses the point. When aiming for excellence, part of the process is to be empowered to explore the performance envelope of your production capabilities fully."

Anyone who follows elite sport or competition in whichever discipline will recognise that, even though the equipment used by the athletes looks like the kit you can buy in the shops, the reality is that the competition product is honed to be the very best of its type. It's hard to offer this level of performance to the public at an accessible price point. The Atherton team's ambition is to overcome this. Whilst Atherton machines at their peak factory race team specification will command a hefty five-figure sum for the highest group-set specification, the entry-level product is priced to be accessible to those dedicated to their chosen sport. The frame itself is the most stable element of the overall bike cost and a well-set up entry-level product in the Atherton range will be a revelation to most riders. If you want even more performance, it's a matter of increasing your component budget or as well as exploring the twenty or so frame options that Atherton offers.

Safety in numbers

Atherton is not alone in the pioneering use of advanced AM technologies in bike production and there is clear potential for metal AM applications beyond the frame itself. The golden rule is to avoid using metal AM just because you can; the technical demands of the component must lead the choice. If an alternative process can do a better job, then use it. The obvious advantage of access to your own metal AM system is the opportunity for experimentation that it permits; this is where future innovations will be born.

As for production parts, once a design is stable and the process variables are understood, it's possible to have a blend of in-house supply combined with a capable subcontract supply chain to support production demand fluctuations.

We will continue to watch Atherton's AM journey with interest. Having visited this passionate, young and dynamic team, it's clear that all the ingredients for continued success are very evident. So, keep up the metal bashing!

Fig. 10 Tested to the limits by Gee Atherton (Courtesy Atherton Bikes/ Dan Griffiths)

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A game of hide and seek with Renishaw and Altair: AI-powered quality assurance on the fly

Is it possible to actively monitor the huge volumes of data from a Laser Beam Powder Bed Fusion (PBF-LB) machine to identify, through machine learning (ML), build errors as they happen? To answer this question, Renishaw and Altair played a unique game of hide and seek. In this innovative experiment, an error was deliberately hidden in a build for an artificial intelligence (AI)-based solution to find. The hope? True 'on the fly' quality assurance for Additive Manufacturing processes for accelerated product development, and dramatically reduced post-production quality checks.

Quality management in metal Additive Manufacturing is one of the biggest challenges faced by today's producers on their way to mass production – potentially requiring extensive process monitoring and the physical testing of every single part produced. In an effort to improve process monitoring and reduce the extent of non-destructive testing from, for example, a 100% CT scanning-based qualification processes, Renishaw and Altair set out to explore new possibilities using artificial intelligence (AI). The focus of the project was to develop a methodology to analyse the incredibly large quantities of manufacturing data generated. Putting AI to the test, the two companies sought a novel way to simplify quality control and potentially accelerate the qualification process, paving the way toward AI-powered, real-time meltpool analytics.

Laser Beam Powder Bed Fusion (PBF-LB) is the most well-established metal Additive Manufacturing process, using 3D model data and a laser (or, increasingly, multiple lasers) to selectively melt and fuse powder layer after layer, enabling the production of complex parts and structures. While metal Additive Manufacturing offers many benefits for innovative industry verticals such as aerospace and medical device production (for example, the use of difficult to work materials, mass reduction and the reduction of material waste), manufacturing defects must still be avoided and the highest quality standards adhered to.

In addition to conventional geometric, dimensional, and surface quality requirements, the characteristics of the metal material itself are under incredible scrutiny. Factors such as density, stiffness, strength,

Fig. 1 Renishaw's flagship machine, the RenAM 500Q, with in-situ monitoring of the meltpool at the powder bed (Courtesy Renishaw)

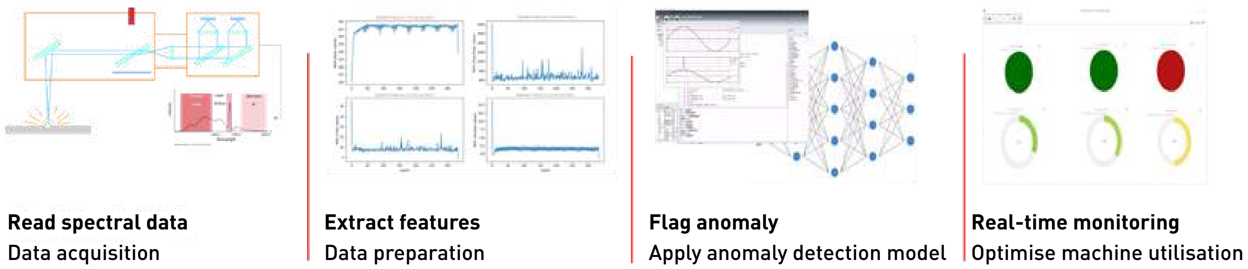


Fig. 2 AI-driven quality assurance for manufacturing process overview (Courtesy Altair)

fatigue resistance and, increasingly, conductivity, are subject to unprecedented analysis.

Many of the most critical applications for additively manufactured parts demand stringent quality checks after production. Typically, these inspection processes are time consuming and expensive. To reduce this effort, engineers are constantly seeking ways to detect manufacturing defects on the fly, which means while the production process is still running. To do so, engineering teams need to establish a monitoring process for equipment to ensure stability and productivity throughout the entire operation.

Scan to find scrap

Physically inspecting the entire production output of a metal AM machine is an incredibly inefficient way to work and, indeed, is widely seen as one of the biggest hurdles to the widespread adoption of the technology in production scenarios. In many other production processes, a subset of manufactured parts is inspected in numbers that provide a statistically derived confidence in the stability of the process. However, given the relative newness of metal AM, there is not the same wealth of experience and data against which production engineers can compare output. This is particularly true in cases of brand new products – which many AM parts are.

Renishaw and Altair's experiment, therefore, set out to see if their existing AM and AI expertise could be brought to bear in simplifying the quality control process for end-users. As well as being a manufacturer of PBF-LB AM machines, Renishaw is a leader in the fields of process control and automation. In the 1970s, Renishaw gave the world the touch-trigger probe device, found in machine tools and CMMs across the globe to this day.

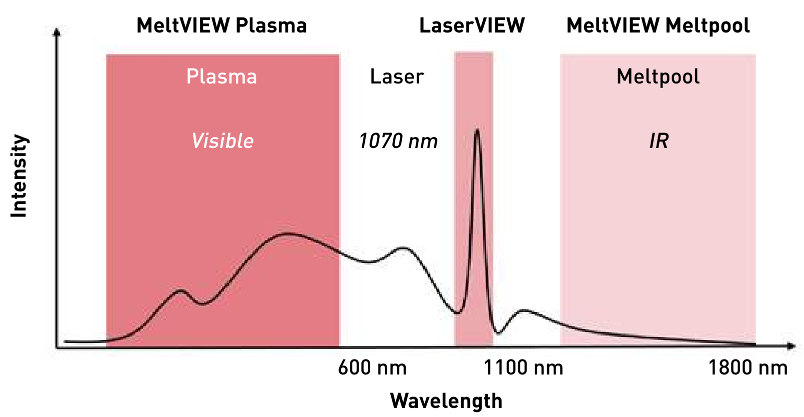


Fig. 3 Light spectrum analysed in the process monitoring. Adapted from: Meas. Sci. Technol. 21 (2010) 105705 (Courtesy Renishaw)

In the intervening years, Renishaw has become a market leader in the fields of machine calibration, positional encoders, and healthcare device production. Altair is a global leader in computational science and artificial intelligence that provides software and cloud solutions in simulation, high-performance computing (HPC), data analytics, and AI. In an experimental setting, the two companies brought this expertise together to put artificial intelligence to the test with the aim of answering two questions:

- Can AI find anomalies in a single sample hidden among many, without knowing what or where the anomaly is?
- Is it possible to use inline machine learning routines to find an automated gauging process and reduce the burden of non-destructive testing?

The starting point: It's all in the data!

Renishaw's flagship Additive Manufacturing machine, the RenAM 500Q, has four 500 W lasers and a build volume of 250 x 250 x 350 mm. The machine offers automatic powder and waste handling alongside one of the most innovative, precise and repeatable digital optical platforms on the market, from proof of concept to volume production. Rather than sourcing a third party process monitoring solution, Renishaw developed its own solution for in-situ monitoring of the meltpool at the powder bed. By doing this, it

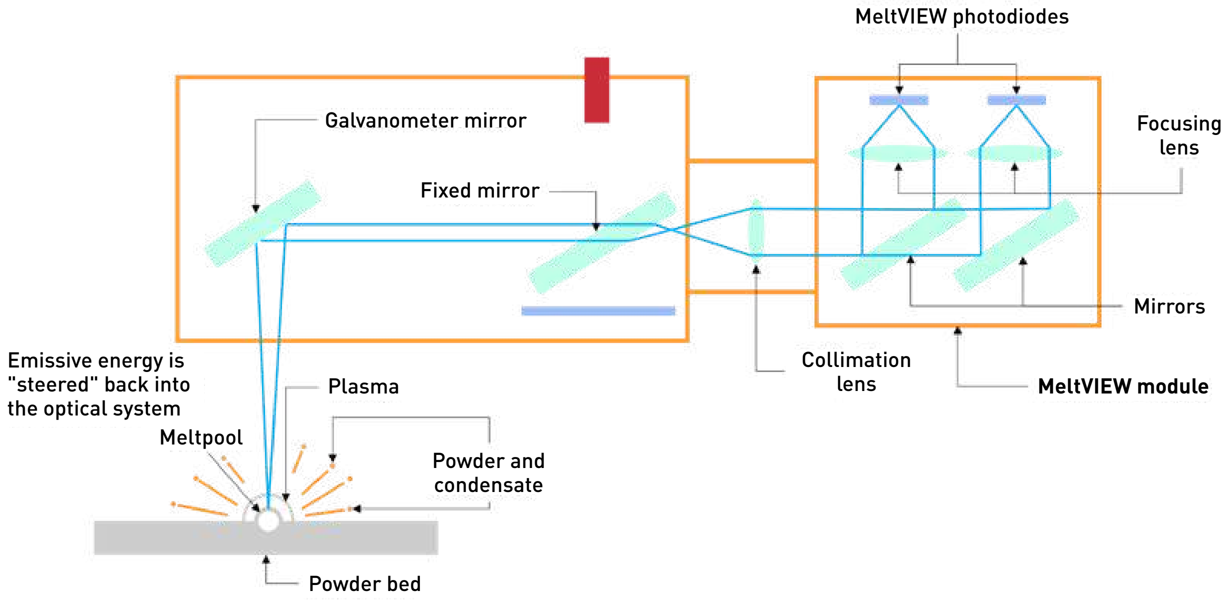


Fig. 4 Schematic illustration of meltpool monitoring (Courtesy Renishaw)

has the capability to 'lift the curtain' on the data to a greater extent than is the case in many other similar PBF-LB systems.

During the build process, light is emitted from the meltpool in various forms. Of particular interest are the wavelengths corresponding to plasma (visible) light and infra-red (invisible) light. In addition, it is beneficial to monitor the wavelength corresponding to the laser itself. By steering these spectral emissions through the optical head and onto a bank of photodiodes, it is possible to sample the intensity of emissions relative to their corresponding 3D position in space. The sample rates in use are extraordinary: typically in the order of 100 kHz, or about 20,000 samples in the time it takes to blink. Such incredible rates of data capture lead to a significant data storage demand.

To help in using the data, Renishaw's software solution, InfiniAM Spectral, filters and renders a graphical representation of the data in a conventional Windows environment. From here, it is an intuitive process for an engineer to browse through the 2D layers of data, or indeed view a 3D representation of the additively manufactured part, coloured according to the intensity of the signals received.

While intuitive to view, there is still a degree of experience required on the part of the engineer viewing the data. There can be so much data available that it is sometimes

Fig. 5 Renishaw's software solution: InfiniAM Spectral visualisation Build data from hardware sensors are viewed in Renishaw InfiniAM Spectral software (2D and 3D) (Courtesy Renishaw)

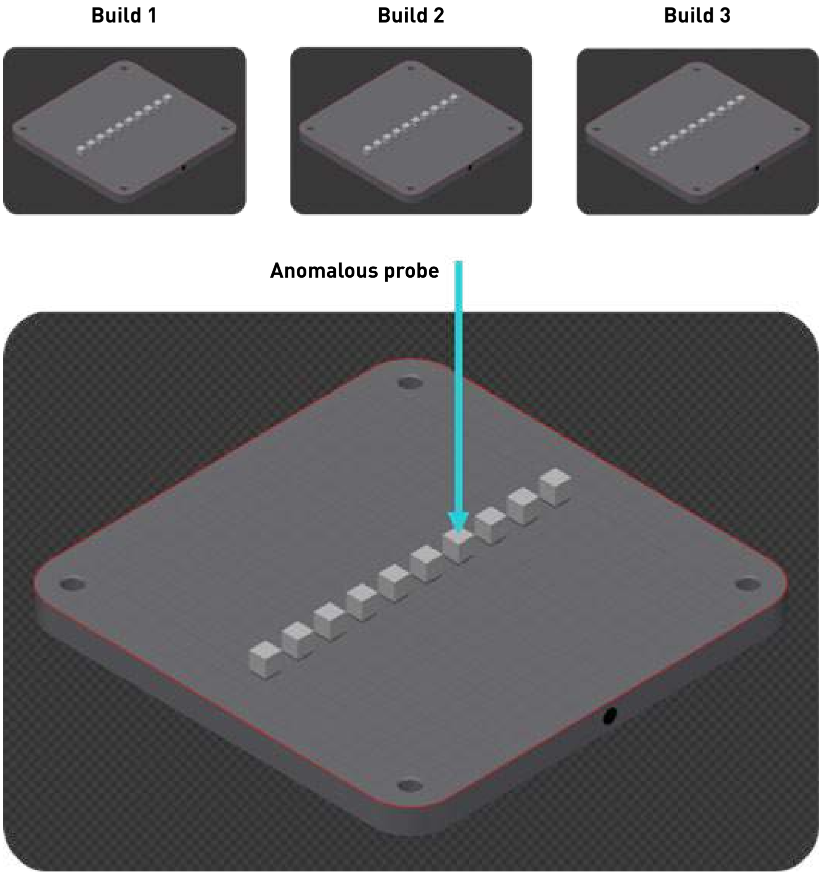


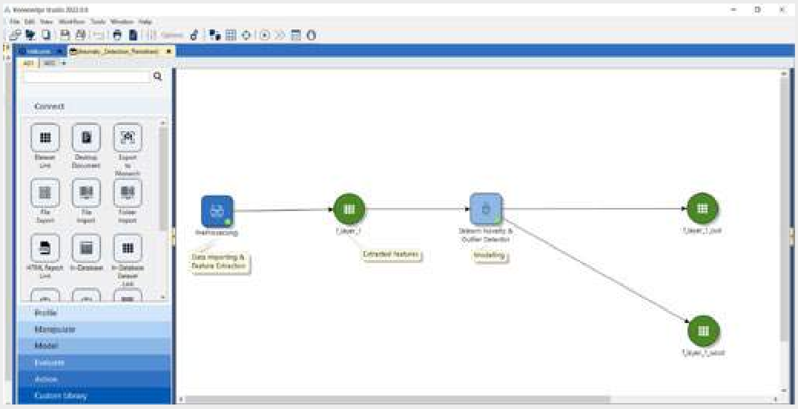
Fig. 6 Hide and seek test setup: three builds with ten probes (Courtesy Renishaw)

difficult to interpret in an effective manner. To that end, automating the process – especially in real-time – could be a real boon to the end-user. Given the sheer volume of data involved, machine learning makes logical sense to implement. This is where Altair's AI technology comes to the forefront.

Finding the odd one out: Flying blind

As machine learning (ML) algorithms have become more accurate with increased computation power, engineers can now depend on ML technology to make decisions from data without compromising floor efficiency. To leverage this technology, Renishaw asked Altair to dive deep into the data in a special test. Renishaw wanted to use Altair's AI technology to flag anomalous builds, and regions within those builds, by analysing spectral data in real time, enabling quality assessent on the fly without the need to wait until production ends.

Altair's signalAI



Data pre-processing and modelling in Altair Knowledge Studio using the signalAI tools (Courtesy Altair)

Altair signalAI is a versatile tool which augments the power of signal processing with machine learning to perform sensor signal-based predictive analytics. It is designed to address various types of use cases under the predictive maintenance umbrella with a special focus on anomaly detection, fault classification and root cause analysis. In terms of capabilities, on the data preprocessing front, signalAI offers both time and frequency domain feature analysis and, on the analytics front, currently it supports several state-of-the-art anomaly detection models off the shelf.

Within Altair's product line, signalAI is available with Altair Knowledge Studio® as well as in Altair Compose®. Following the broader Altair theme of 'low code/ no code' environment, signalAI is also designed by keeping ease of use for the users as the primary focus and, hence, can be controlled via drag and drop with minimal effort from the user. On top of this, for the purpose of end-to-end deployment, signalAI can be hooked up with Altair SmartWorks IoT if there is a need for real-time data stream monitoring and Altair Panopticon for end-point inference and result visualisation and dashboarding.

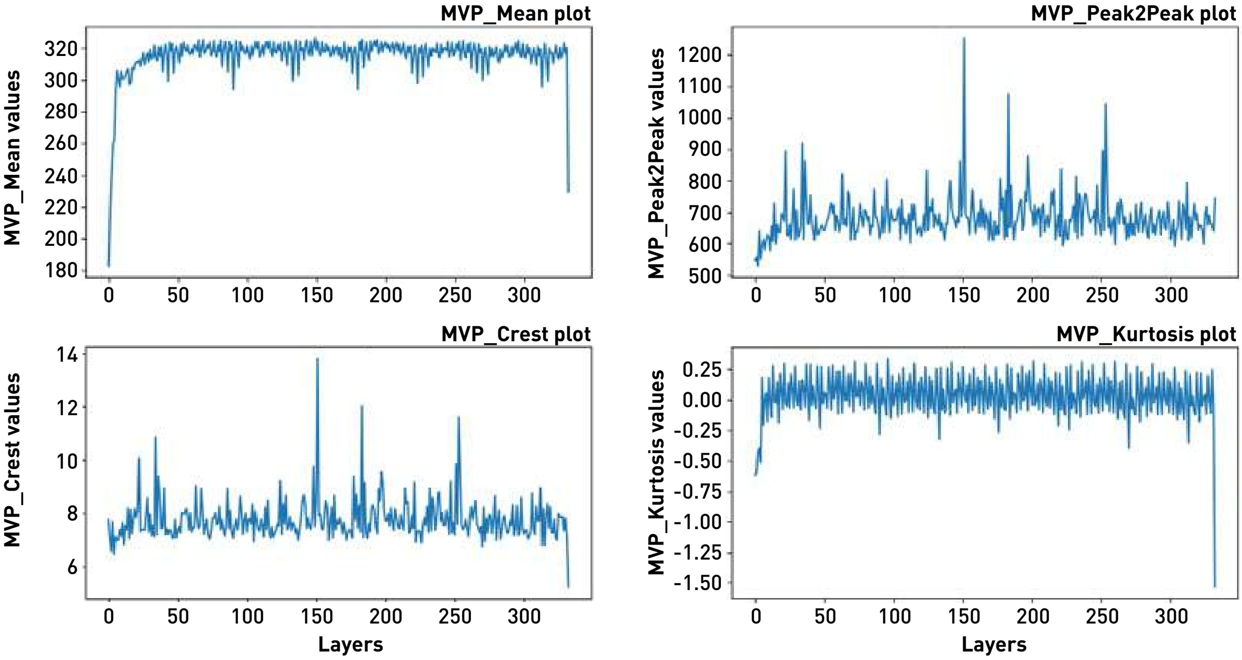


Fig. 7 Data reduction to statistical features in time-domain (Courtesy Altair)

The task for Altair was to set up a data model for the automatic detection of nonconformities and, in effect, create an in-situ decision making toolset. The test consisted of three physical cobalt chromium builds on the Renishaw machine: each build containing ten standard 10 mm density coupons, so thirty coupons in total. In one of these thirty blocks, there would be a deliberately induced non-conformity. Altair was provided no information as to what had been done and where. Moreover, Altair was not provided with any baseline for what 'good' even looked like. Altair was more or less 'flying blind', only able to see what the quality assurance model was able to identify. The task was split into two levels:

- **Build:** Detect the non-conforming print
- **Region:** Detect the 3D region or volume of interest within the non-conforming build.

From data to insight

To turn the data into useful insights, four major steps are required:

1. Data acquisition
2. Preparation
3. Anomaly detection
4. Visualisation or real-time monitoring

As the spectral data are captured with a very high sampling rate, the initial step for Altair is data pre-processing. In a function referred to as 'feature engineering', five time domain statistical features are extracted per layer. This reduces the noise in the raw data and accelerates the training process of the downstream anomaly detection models. Another positive effect of this pre-processing is a reduction in the sheer size of the raw data.

To identify anomalies, Altair uses three different approaches: hyperplane, density, and tree-based algorithms. The extracted features from the data preparation process are fed into SignalAI to identify the algorithm best suited to distinguishing the outliers. After applying various options, a tree-based method proved best for the application. When comparing the algorithms, two factors stand out. Analysing each spectral parameter independently, the tree-based algorithm flagged Build 3 as the anomaly unanimously. So, it is very consistent in its prediction. On top of this, the tree-based algorithm also has higher confidence scores for its predictions. Once the third build was identified, the same process was repeated and an anomaly corresponding to the fourth block of that build was successfully detected.

"The test consisted of three physical cobalt chromium builds on the Renishaw machine: each build containing ten standard 10 mm density coupons, so thirty coupons in total. In one of these thirty blocks, there would be a deliberately induced non-conformity."

HYPERPLANE BASED ALGORITHM								
Features used	**Algorithm**	**B1**	**B2**	**B3**	**CS_B1**	**CS_B2**	**CS_B3**	**Anomaly**
LaserView	HPA	**310**	23	0	0.55	0.55	0.55	Build 1
MeltVIEW Plasma	HPA	**332**	0	1	0.55	0.55	0.55	Build 1
MeltVIEW Meltpool	HPA	191	131	**10**	0.55	0.55	0.55	Build 3
Inconsistency in the prediction B1, B2, B3								
DENSITY BASED ALGORITHM								
Features used	**Algorithm**	**B1**	**B2**	**B3**	**CS_B1**	**CS_B2**	**CS_B3**	**Anomaly**
LaserView	DA	84	**249**	0	0.99	1.01	0.99	Build 2
MeltVIEW Plasma	DA	**93**	119	121	0.99	1.01	1.01	Build 1
MeltVIEW Meltpool	DA	58	79	**196**	0.97	0.99	1.06	Build 3
Inconsistency in the prediction B1, B2, B3								
TREE BASED ALGORITHM								
Features used	**Algorithm**	**B1**	**B2**	**B3**	**CS_B1**	**CS_B2**	**CS_B3**	**Anomaly**
LaserView	TA	0	0	**333**	0.19	0.19	0.28	Build 3
MeltVIEW Plasma	TA	17	3	**312**	0.21	0.20	0.25	Build 3
MeltVIEW Meltpool	TA	145	152	**32**	0.23	0.23	0.20	Build 3
Consistency in the prediction B1, B2, B3								
Higher spread between the inlier and the outlier, results in higher confidence scores								

Table 1 Benchmarking the algorithms. Comparison of the prediction consistency and confidence scoring (Courtesy Renishaw and Altair)

Renishaw confirmed the automated prediction when they revealed that the fourth block in the third build was indeed anomalous. In this case, the laser power used for hatching the block was dramatically reduced from standard processing conditions. The effects were also borne out in the Archimedes density measurements, reflecting one of the many various inspection techniques in use today. Note the very subtle difference in Archimedes measurement for a 50% reduction in laser power.

This data-driven model can detect anomalies and assign them to a corresponding area of a build job. From the implementation perspective within Altair's product line, data analytics was successfully performed using in Altair Knowledge Studio® as well as in Altair Compose®. Expanding on this, adding Altair® Panopticon™ dashboards can be used to visualise and monitor the final results in real time if continuous remote monitoring is required.

"Renishaw confirmed the automated prediction when they revealed that the fourth block in the third build was indeed anomalous. In this case, the laser power used for hatching the block was dramatically reduced from standard processing conditions."

Reducing the burden of non-destructive testing

The Altair tool was used to successfully detect anomalous builds during the metal Additive Manufacturing process. Without any prior knowledge of previous build characteristics, the software was able to successfully determine a non-conforming build and region of interest within that build. The potential of machine learning capability to actively monitor data from manufacturing runs immediately became apparent to the teams at Renishaw and Altair. The opportunity for manufacturing teams to reduce or eradicate physical comparison and detailed inspection of datasets and parts should not be underestimated; the potential time and cost savings could be a leap forward in enabling rapid certification of additively manufactured products.

signalAI's anomaly detection software can be used in real-time locally or remotely in the cloud and includes

Build 1 results										
Sample	1	2	3	4	5	6	7	8	9	10
Density (g/cm³)	8.367	8.372	8.373	8.374	8.372	8.372	8.372	8.370	8.731	8.365
Build 2 results										
Sample	1	2	3	4	5	6	7	8	9	10
Density (g/cm³)	8.364	8.361	8.362	8.363	8.364	8.353	8.356	8.359	8.357	8.355
Build 3 results										
Sample	1	2	3	4	5	6	7	8	9	10
Density (g/cm³)	8.356	8.354	8.36	8.292	8.359	8.357	8.358	8.355	8.358	8.356

Build 3 hatch settings										
Coupon (left and right)	1	2	3	4	5	6	7	8	9	10
Hatch power (W)	180	180	180	90	180	180	180	180	180	180

Table 2 Archimedes density testing data proving the capability of the machine learning, confirming the sample 4 in build 3 being the outlier (Courtesy Renishaw)

pre-processing capabilities, allowing complete model builds and analysis to be completed within a single platform.

Making way for the future: metal AM goes AI

For manufacturers using metal AM technologies, these tests suggest that AI could enable them to reduce the burden of non-destructive testing by sorting out the candidates where anomalies occurred. Instead of scanning every single part with a CT scanner, the software can tell them which component will not pass the quality check. This method allows a faster and more precise pre-qualification of parts. In the future, this could save up to 90% of inspection efforts, resulting in an enormous increase in efficiency. Another benefit is that this methodology can be added to an existing quality assurance system, hence using existing resources. As quality assurance happens during the production process, this is a closed process, an in-situ quality assurance, paving the way to short-term and long-term advantages.

Implementing data-driven decision making from the ground up allows design and manufacturing teams to holistically analyse processes to improve an organisation's smart

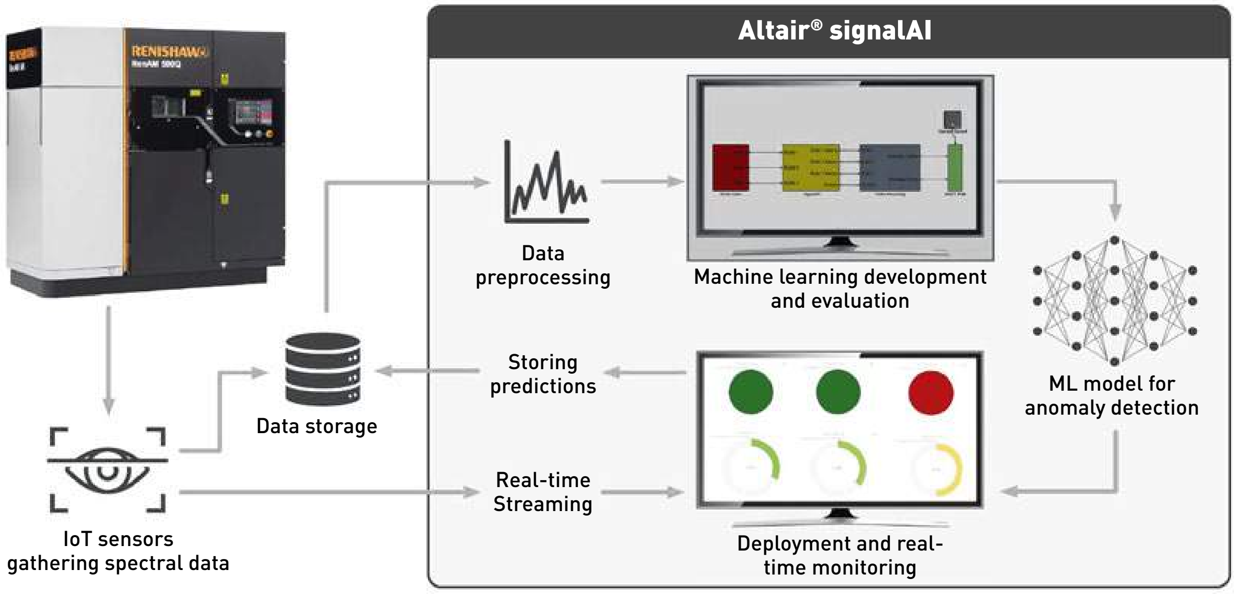


Fig. 8 Overview of the solution scheme Altair signalAI driven quality assurance for manufacturing processes (Courtesy Altair)

factory practices. Looking forward, an AI-driven manufacturing approach offers endless possibilities for machine improvement, such as identifying the best sensor type and location for an application, and shared learning to improve processes within an enterprise with a hybrid cloud approach.

Short-term benefits

- Faster and more accurate part qualification
- Reduce the burden of non-destructive testing
- Simplify QA for serial production
- Augment existing QA strategy with minimal disruption
- Reduced data storage as only non-conformance is of interest

Long-term benefits

- Characterise defect formation and identification
- The basis for true closed-loop processing
- Potential to revolutionise production certification for AM
- Speeding up the entire production and qualification process, paving the way for cost efficient mass production

Reducing the number of non-destructive tests – particularly for safety-relevant components in aerospace or healthcare – can help manufacturers worldwide to cut down on quality assurance effort and cost and take another big step towards lean manufacturing. As quality management in metal AM has always been a major bottleneck for mass production, looking for ways to reduce or, perhaps, even eliminate this obstacle might be the biggest advantage manufacturers can now look forward to. This novel method of in-situ quality assurance could pave the way for a whole new manufacturing world.

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www.altair.com



Opening the discussion: How the humble bottle opener demonstrates the importance of requirements in AM

Designs not driven by requirements increase the risk of an incomplete solution. This relatively simple statement gets to the heart of how designers need to be approaching AM, particularly when balancing the 'design freedoms' offered by the technology with the reality of viable and profitable production. Through an exploration of the ubiquitous AM bottle opener, John Barnes, Jennifer Coyne and Chelsea Cummings, The Barnes Global Advisors, and Jon Meyer, APWorks, explore how, by focusing on requirements, a data-driven approach ensures fully functional designs that deliver on multiple requirements for the lowest cost.

Requirements get a bad rap at times. It is difficult to look forward to something that is required; if it were fun to do, why would it be required? Much like eating vegetables, though, requirements provide the sustenance for us to grow and a structure to be successful. Requirements can also often be quite broad and create an opportunity for entirely new solutions, much like Dyson's approach to a vacuum cleaner, or prototypes of the stealth fighter – they challenged the status quo. Often, when there is a qualification activity looming in the distance, requirements take on a much more comprehensive, restrictive, and narrow focus.

Requirements often contain not only technical considerations, but commercial, environmental, and sometimes aesthetic. Often, only the purely technical requirements are discussed, because they appear more concrete and obvious. However, in Designing for Manufacturing (DFM), one or more of the categories of requirements routinely converge. This is partly because manufacturing processes inherently have limitations, so making the right choice impacts the business case and is necessary and hard. It is harder yet for Additive Manufacturing because AM is still new, so there is perceived risk, which typically drives the 'cost of change' conversation. However, it is necessary to consider the other factors and how they contribute to the overall case to adopt AM:

- Technical: Form, fit, and function
- Commercial: Pricing and quantity
- Aesthetic: Appearance and consistency with the brand of the company or the individual
- Environmental: Carbon footprint, waste generation, and end-of-life disposal

Clearly, there is a link from the requirements to DFM. DFM helps to ensure the requirements are met given the manufacturing process, which includes the cost targets by considering the entire process holistically. In AM, this includes

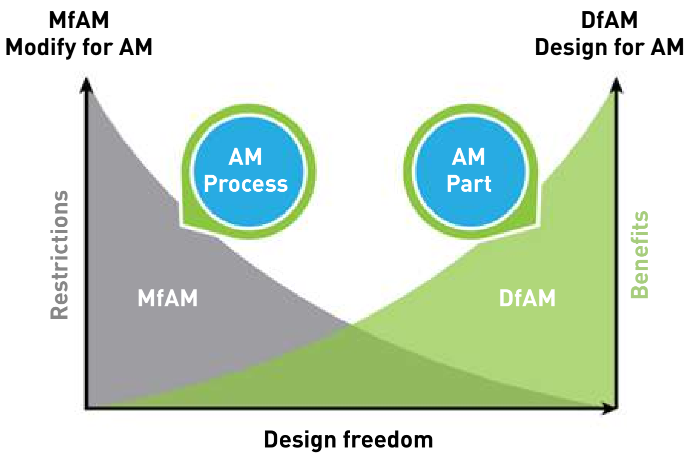

Fig. 1 The opportunistic and restrictive design space: DfAM and MfAM

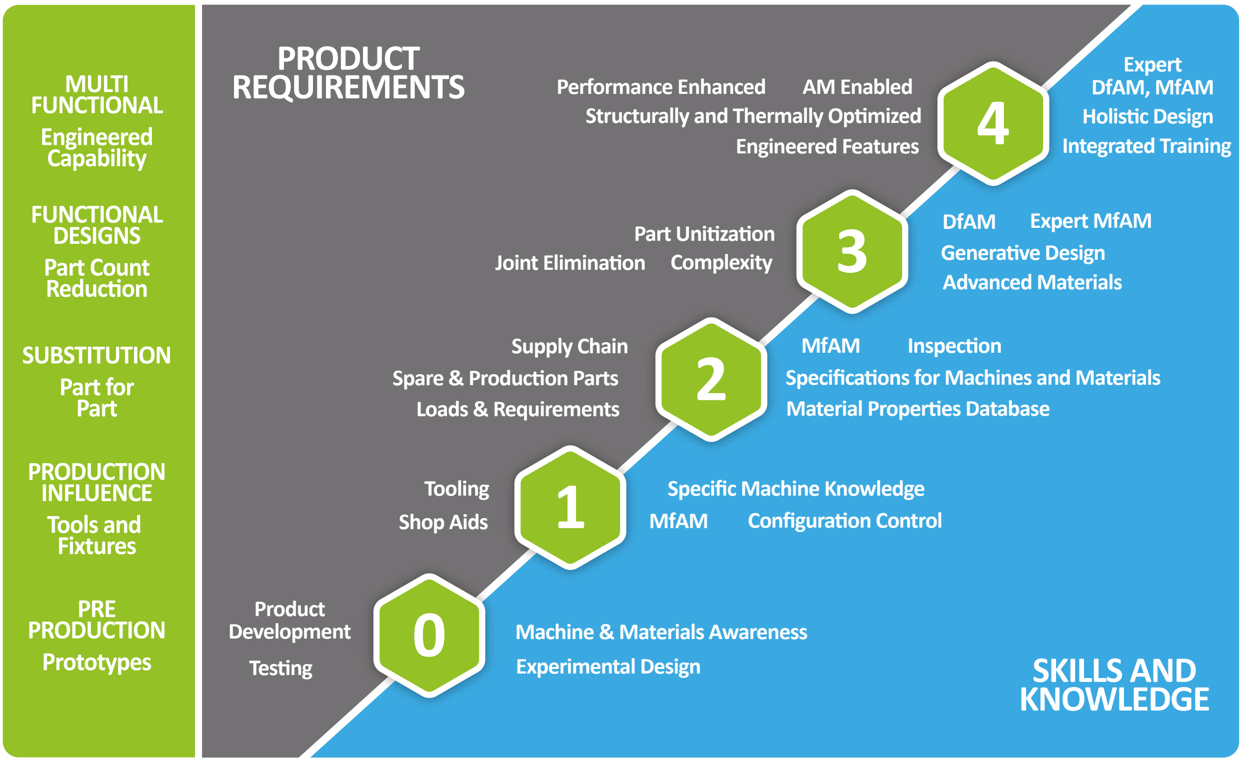

Fig. 2 The TBGA AM maturity model

before and after the build itself, which must be reflected in the design: this is what is called Designing for AM (DfAM).

Within Designing for AM, it can be useful to further subdivide the design space into DfAM and Modify for AM (MfAM). DfAM is typically associated with benefits of where there is a lot of design freedom. We refer to this as *opportunistic*, because we extoll benefits provided by the design of an AM part. MfAM is more associated with the restrictions or lack of design freedom, so we refer to this as *restrictive*. MfAM tends to be more closely oriented with the AM process and its influence on the part.

Opportunistic

This reflects the limitless possibilities where the design can look like a plane that surely can't fly, yet meets all of the many requirements, including flight safety. The solution allows the consolidation of parts or incorporation of multifunction – supports that serve as cooling channels or a bottle opener that can be converted to a screwdriver. With a new part or design, there is often less constraint coming than in modifying a current product.

Restrictive

This often deals with the realities of manufacturing, so it is heavily dependent on the AM process. The orientation of the part and the build layout forces the choice between shorter builds with fewer parts and longer builds with more parts. Other considerations include adding stock for a subsequent machining step and leaving datums for the machinist. MfAM is pervasive at all levels and is a companion to DfAM. An example is creating a replacement for a part created by a traditional manufacturing process like casting, where there is no option to change the design.

As Fig. 1 highlights, MfAM helps deal with the elements where our design flexibility is limited, whereas the freedom of DfAM enables further performance and opportunity. The product will have requirements, which must have a commensurate skill and knowledge capability. The TBGA AM Maturity Model (Fig. 2) uses levels to describe the product requirements, skill and knowledge required to meet them. Within that, Level 2 is typically where the design space is Restrictive and where MfAM dominates, because it is a part for part swap. Levels 3 and 4 represent the Opportunistic space, where design and performance are optimised. Here, DfAM tends to dominate, but MfAM exists.

There is a quote attributed to Albert Einstein that says, "If I had an hour to solve a problem, I'd spend fifty-five minutes understanding the problem and five minutes on the solution." This article explores this concept relative to AM product design and manufacturing through the eyes of requirements. In essence, the first place to start is to study the problem. The ubiquitous additively manufactured bottle opener will be used to explore the concept. Everyone has them; everyone with a metal AM machine has made them. But are any of them really great examples of DFM or Designing for AM? Are they up to the job of opening thousands of bottles of beer at Oktoberfest and surviving Spring Break? This article explores these serious questions and

Fig. 3 Crowdsourced AM bottle opener designs. Top left courtesy Brockton Sterling, Big Metal Additive; top right, photo courtesy Gael Guetard; bottom left, a 3D Systems structurally optimised Ti bottle opener (9.5 g) vs. an extruded and water jet cut bottler opener (25.35 g), photo courtesy Christian Tello; bottom right, photo courtesy Deniz Ince

brings the challenge back to basics. Given the assignment of designing an AM bottle opener, what would be the product brief? Most importantly, what would it look like if an engineering design process were followed?

The process

In the book and movie *Moneyball*, Billy Beane was quoted as saying, "This is a process. It's a process. It's a process." It's true. Beane's data-driven approach to baseball is similar in manufacturing. It's a process. Or a series of processes. The process here was:

1. What problem is being solved?
2. How has it been done before?
3. What are the requirements?
4. What does success look like?

What problem is being solved?
And who cares? The goal of this discussion is to move the AM ball forward. The industrialisation of AM will be hard, it will be a grind. It will be these things because making parts is hard, methodical, consistent work. The design process must consider all requirements and attempt to achieve balance or at least harmony.

A bottle opener essentially acts as a force multiplier. It needs to magnify the force exerted by a person and focus it on the edge of the bottle cap. There are many ways to magnify a force using mechanics, but all involve exerting a small force at distance. Whether pivoting around a fulcrum with an uneven distance on each side, using a screw thread, turning gears with different numbers of teeth, or using pulley blocks, the basic mechanics principle applies. Energy must be conserved (Work = Force x Distance Moved), but you can play with the ratio of the forces and the distances moved.

The typical bottle cap requires a force of about 100 N exerted vertically under the edge in order to dislodge the cap from the bottle. The recommended maximum force for one hand is 45 N, which means the bottle opener will require leverage of at least 2.25:1. This is a good example of opposing requirement; if we optimise for leverage and make it longer, it will cost more. Any increase in the length of the lever results in an increase in the part volume, an increase in the build height, and therefore increased build time and cost. You must meet all requirements, not just one, but there is very rarely a situation where one requirement can be maximised without compromising another.

The next problem, and possibly the highest-ranked requirement, is that the bottle opener should represent the brand and potentially the brands of others, which means design freedom (opportunity) is important. The device should also be useful over the long term, so it does not end its life in a landfill.

How has it been done before?
Surveying the industry (thank you to all who weighed in on LinkedIn!) and the kitchen, the examples in Fig. 3 exhibited some common qualities of the average AM bottle opener:

- Produced out of metal

Requirement	Description
The design shall not fail by fatigue	Technical. Fundamentally, the opener must not fail and must be designed for infinite life
The weight shall be less than 75 g	Technical & commercial. The mass to be produced correlates to cost in some proportion either through material consumption and/or build time
The design shall generate leads	Aesthetic & commercial. The goal is to start a conversation. To do that, it should be the bottle opener of choice (multi-purpose), incorporate cool features (lattice, QR code, etc.)
Ergonomic features shall be incorporated into the tool	Aesthetic & technical. It should be a topic of positive conversation and not how hard or uncomfortable it is. It should be useful to both left and right handed people
A logo shall be incorporated	Aesthetic & commercial. The logo is key to the brand and so it must be incorporated into the design
The cost shall be less than $50 per piece	Commercial & technical, aesthetic, environmental. While high, a $50 item could still be in the solution space and the price will be driven by the combination of requirements
The design shall use MfAM principles to 'print and go'	Commercial & technical. Predominantly, this is a commercial requirement, but it will be dominated by MfAM
The design shall use minimal processing	Commercial & technical. Predominantly a commercial requirement, the ability to design for AM, including material selection, affects the need for post-build processing
The product shall incorporate elements of sustainable design	Environment. There was a desire to at least examine the impact, which could be as simple as recyclability or more complex such as infinite life so it wouldn't wind up in a landfill

Table 1 Requirements list

- Usually surface finished
- Optimised for maximum build quantities
- Designed to fit on a keychain
- Displays a logo
- Cost-efficient

Fundamentally, the designs in this space fell into two categories: lever-focused or artistic. Of the several bottle openers examined in the writing of this article, there were few with any reference to requirements and many that claimed to be the lightest. Without a shared set of requirements, it is dubious to claim this feat but the enthusiasm to drive design thinking is commendable.

Levers

The levers that worked best were typically thin and not very long. From the author's laboratory research, the tendency to excessively deform or crimp the cap was a common complaint, resulting in additional effort required to remove the cap. Comments from colleagues ranged from 'the surface finish snags my clothing' to 'mine is the lightest ever.' These designs are heavy on MfAM in an effort to keep the cost down and ranged in the application of DfAM. There was one with the driving need to open the bottle in one continuous motion.

Artistic

The artistic approaches inherently relied more on DfAM. They included additional features (or just more elaborate designs) that would be more costly, but would act as conversation starters. Their ability to open a bottle might have been a secondary consideration.

Legacy

Bottle opening is a need that predates Additive Manufacturing, so inspiration also came from what is used at home. This ranged from gifts that had sentimental value and worked well, to aesthetic designs that would look nice on the counter; these designs also tended to easily open the cap.

What are the requirements?

After reviewing the existing solutions, the next step is to define the requirements for this product, starting with what problem is being solved. Given so many AM options, what keeps them from being the only bottle opener ever needed? There are usually a couple of main factors: ergonomics and efficacy. If it is not easy to use nor always effective on the first try, then it will never dethrone the traditional bottle opener kept on the patio for Sunday barbecues. With that in mind, a list of requirements was established, shown in Table 1.

Results

What was the outcome? All the solutions met the stated requirements. As expected, the team of amateur and semi-amateur designers all took different approaches to meet the requirements. Iterations occurred as their designs evolved.

Fig. 4 Long Handle Lever

Fig. 5 Barnesy's Bottle Opener 'The Disc'

The most important thing was learning what it actually takes to open a bottle. For those that have brewed their own beer, the next to last step is capping the beer, which involves a process to deform the cap 'blank' over the top of the bottle (the last step is enjoying said beer – responsibly, of course). Understanding this step and the mechanics or loads required to remove the cap can make the difference between doing this easily with little effort and simply deforming the cap without removing it.

Each of the designers (authors) took different design paths based on their interpretation of how best to meet requirements. While MfAM drove their initial thinking, they departed by exploring the opportunistic space (DfAM), strongly influenced by the aesthetics of the designer.

The Coyne Conundrum – Long Handle Lever

Jennifer Coyne came up with the first concept shown in Fig. 4. It could be described as the utilitarian's go-to bottle opener, as the design intent aimed to incorporate at least one other aspect of functionality, making it a Level 4 design. Coyne's design incorporated a Phillips-head screwdriver, as it is commonly needed and not easily substituted. For Coyne, this may have been top of mind after installing batteries in way too many children's toys over the holidays.

To maintain a safe and ergonomic user experience, the Phillips-head was designed as detachable, fitting into the same end of the bottle opener as the detachable bottle opener structure. With both tools on the same side, they benefit from the ergonomic grip handle common to most screwdrivers and lever-type bottle openers. The detachable bottle opener simply inserts and twists into a seated position, upon which the bottle-opening load backs up to an internal wall. There is certainly an advantage and perceived value in a tool that has multiple common functions integrated.

Barnesy's Bottle Opener – The Disc

John Barnes took an approach with his concept that could be described as the conversationalist's 'go-to' design (Fig. 5). It captures the essence of bottle opening in function, and arguably in feeling, by its 'meta' looking design. Resembling a bottle cap itself, this concept is round, slim and small enough to fit ergonomically in one's palm, yet not so small it fails to distribute the load of the bottle cap and cause crimping of the edge of the cap without actually prying it off.

Logos are prominently featured and it would be a single piece for ease of manufacture/assembly. This design is easily slipped into a pocket or a briefcase and won't set off airport alarms. It could nest well and would not increase Z height for build time.

Meyer's Marketing Tool – The Shaped Lever

Jon Meyer was inspired by the underlying problem which the AM bottle opener solves – how to promote your business and technology beyond your immediate network. The bottle opener is just one of many mechanisms to start a conversation about a business or technology. It is inherently social, starting with, "Hey, has anyone got a bottle opener?" and could lead to – well, leads. The AM bottle opener is a marketing tool more than a mechanical device, but it still needs to

Fig. 6 Meyer's Marketing Tool 'The Shaped Lever'

	Max Stress (MPa)	Hand Force (N)	Hand Pressure (N/mm²)	Mass (g)
Requirement	**<80 MPa**	**<45 N**	**< 0.2**	**Minimize**
Disc	150	31	0.085	41
Long handle	290	52	0.063	66
Shaped lever	37	36.6	0.128	23
Narrow lever (baseline)	37.5	91.4	0.447	14

Table 2 Max stress, force, pressure, and mass of the concepts.

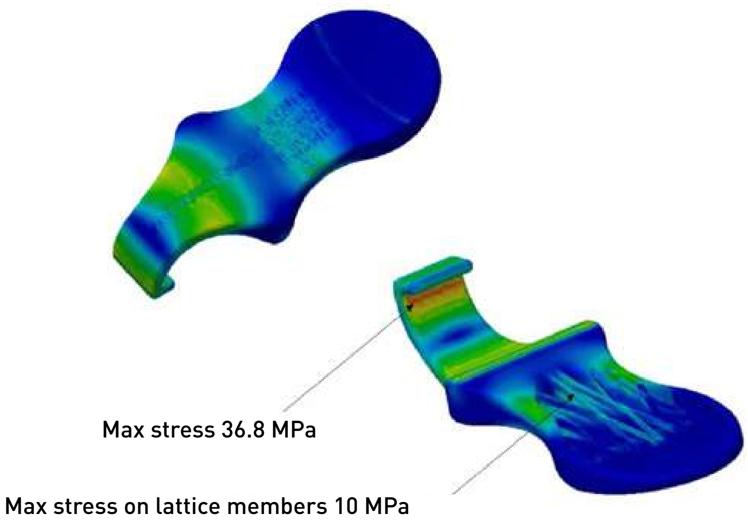

Fig. 7 The Shaped Lever (max stress 36.8 MPa)

work. As Meyer points out, marketing is not a perfect science, but a titanium bottle opener that breaks in half is not a great marketing tool for a company that is making titanium hip implants.

Brand awareness is, therefore, critical for an effective marketing tool; this design incorporates a prominent logo and a QR code that links to the landing page on a website shown in Fig. 6. Jon's design enables some data generation to capture website traffic and, ultimately, cost per lead generated. If the goal is to spend less than $200 to generate a lead and the design is so clever that each one generates a lead, then it can cost $200. If a lead is landed for every ten produced, then it can cost $20 and not a cent more.

With this in mind, the design is traditional in function (a lever) with a handle shaped to reduce the pressure on the hand while bridging the fulcrum across the bottle cap to avoid it bending/folding. It nests well, easily slips into the pocket, and incorporates some attractive organic structure to start a conversation.

Mechanics and loads: bend but don't break

A very basic Finite Element (FE) model (results in Table 2) was used to estimate the maximum stress and the corresponding pressure in the user's hand. With the maximum stress known, the endurance limit (maximum life) could be determined.

Each solution scored well in at least one technical category, but the shaped lever solution scored well in all technical categories. Figs. 7, 8 and 9 show the results of the FE analysis for each concept. No attempt was made to minimise the peak stresses for the purposes of the article, but this could be easily accomplished.

I'm so tired of fatigue

Why consider fatigue in the design of a bottle opener? It is important to avoid a fatigue failure because none of the requirements will have been met if the product fails to open a bottle. Fatigue in materials is not widely understood, but, as engineers learn to design for Additive Manufacturing, the use of features like lattices will drive more attention to the potential of fatigue as the life-limiting mechanism. But first, what is fatigue? To refresh, John B. dug out his second-year engineering school textbooks (yes, he kept them and yes, they're on actual paper): "If a component or structure is subjected to repeated stress cycles, it may fail at stresses well below the tensile strength and often below the yield strength of the material" [1].

Fatigue is strongly dominated by surface features and other geometry-driven elements, which are where fatigue is likely to be initiated. Rough surfaces, specifically when two powder particles have partially melted can form a nice 'V' shape, which is a perfect initiator, as would be the node of two lattices perhaps at a 90° angle (Fig. 10). In either instance, there is a combination of stress intensifiers to be located and start the crack. Once the crack has started, it will grow with each cycle.

The desire is to design for 'infinite life' by examining the endurance limit for the material and assessing any notch sensitivity. As the focus in this study is on Laser Beam Powder Bed Fusion (PBF-LB), our as-built surface contains a lot of crack initiator 'defects' and a lattice will have many 90° intersections, which will have stress concentrators. Material choices were considered as a material with a higher tensile strength that will also increase the endurance limit, which can help to mitigate design and manufacturing 'defects.'

Bringing it back to the subject at hand, lattice structures were explored as an option to meet the requirements of the ultimate bottle opener, to reduce the build time and materials usage (i.e., cost), but to still make it ergonomic and light. Bottle opening lends itself to fatigue – once a bottle is opened, a second is typically not far off, either because of thirst or colleagues who now know they have the means to quench their thirst as well.

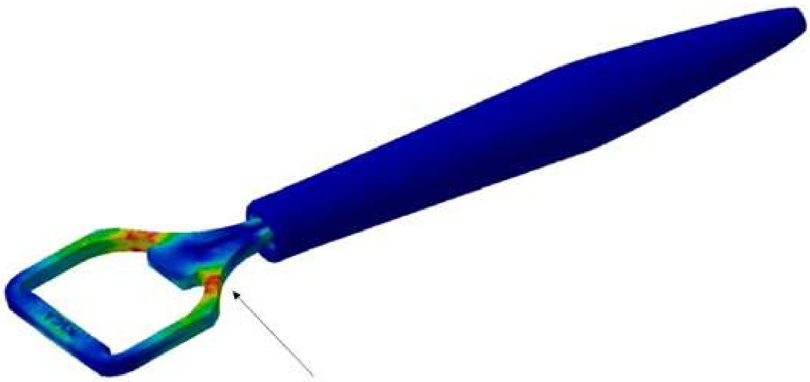

Fig. 8 The Long Handle Lever – max stress 290 MPa, but very localised

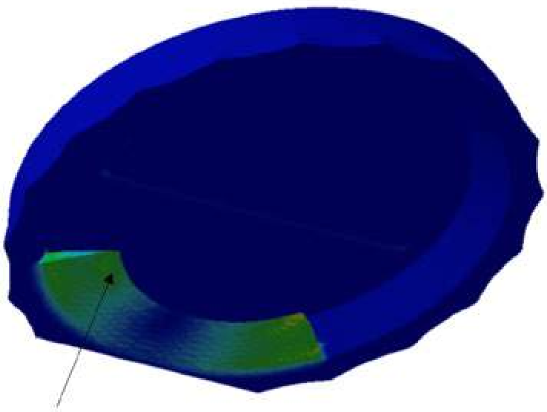

Fig. 9 The Disc – Max stress 150 MPa but very localised in the 'hook' region

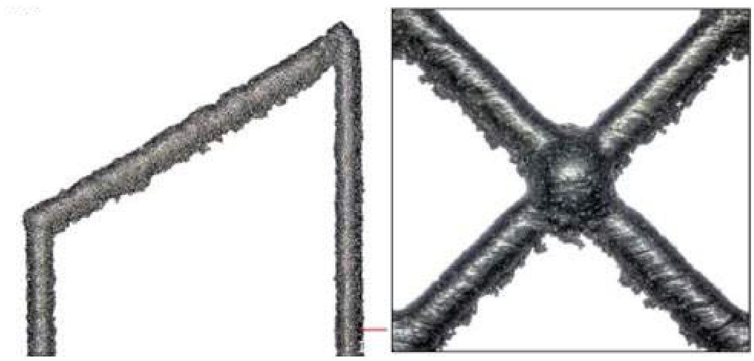

Fig. 10 Left) downward-facing surfaces can exhibit a stair-step effect (design) along with adhered particles (manufacturing). Right). Close up of an intersection point of a lattice highlighting the potential stress concentration and surface defects possible in as built PBF-LB [2]

	Cost/unit ($)
Requirement	**< $50**
Disc	$15.10
Long Handle	$36.35
Shaped Lever	$14.72
Narrow Lever (Baseline)	$10.51

Table 3 Cost per bottle opener of the three concepts and the baseline

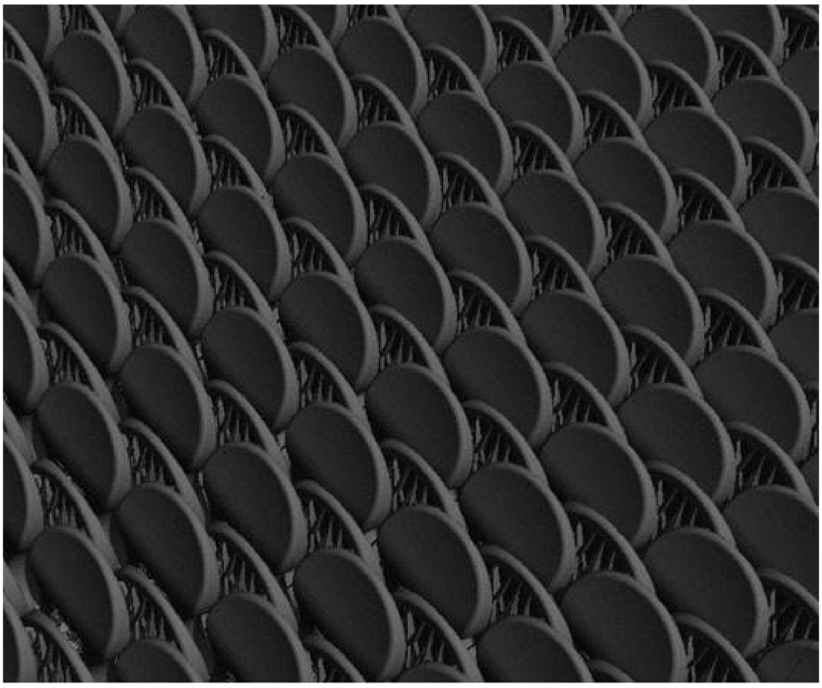

Fig. 11 Maximum build: An MfAM approach to reduce cost with maximum packing

"The point is that bottle opening is a cyclic event, so simply designing to the tensile strength of the material will not ensure successful and infinite bottle opening, especially when using lattices. And bragging that a bottle opener is lighter without factoring in the requirements is really comparing apples to a well-designed and executed apple pie."

The point is that bottle opening is a cyclic event, so simply designing to the tensile strength of the material will not ensure successful and infinite bottle opening, especially when using lattices. And bragging that a bottle opener is lighter without factoring in the requirements is really comparing apples to a well-designed and executed apple pie.

How much does it cost?

Cost is an important requirement in our matrix and there are many factors impacting the cost. MfAM and DfAM must consider the entire process in the part design and layout, otherwise additional costs could be created unintentionally. Some MfAM attributes include nesting, ease of removal from the build plate, and a vertical orientation for a better surface finish. The assessment of the build time, material consumption, and total cost of manufacture was calculated and is noted in Table 3.

The costs were primarily driven by the volume of the parts and their ability to be efficiently nested on the build plate. The baseline solution had the lowest cost, primarily because it had the smallest volume. The slightly more expensive shaped lever was nested with 432 parts on a single build plate in a single layer (Fig. 11).

And the winner is...

How did we determine the winner? A systems engineering approach was taken and each concept was scored against a compliance matrix of the requirements. Table 4 notes the original requirements with a weighting for each requirement and then the scores for each new design and the baseline. To cause more differentiation between concepts, the concepts were rated 9 if they exceeded the requirement, 5 if they met the requirement, and 1 if they did not meet the requirement.

The Shaped Lever achieved the highest score, but all the concepts were very close. Unsurprisingly, the baseline bottle opener designed

Requirement	Weight	Concepts			
		Long Handle Lever	The Disc	The Shaped Lever	Baseline
The design shall not fail by fatigue	9	5	5	9	9
The weight shall be under 75 g	1	5	9	9	9
The design shall generate leads	9	9	9	9	5
Ergonomic features shall be incorporated into the tool	9	9	9	9	1
A logo shall be incorporated	9	5	5	5	5
The cost shall be less than $50 per piece	5	5	9	9	9
The design shall use MfAM principles to 'print and go'	9	5	5	9	9
The design shall use minimal processing	5	5	5	5	5
The product shall incorporate elements of sustainable design	5	5	5	5	5
		377	401	473	365

Table 4 Requirements compliance matrix and scoring

without these requirements in mind scored last. It was noted earlier that the baseline concept scored the lowest overall cost but fails, or just meets, several of the requirements.

"Our data-driven approach ensured a fully functional design that suits multiple purposes for the lowest cost. The initial discussion on what problem was to be solved was worth the investment in time. Requirements are not meant to constrain design, but ensure the best possible outcome and a methodical approach."

Meeting requirements

The requirements can be met with a variety of designs. When taking in opposing requirements, it was critical to weigh some criteria higher than others, because some requirements are more important than others. Opening a bottle cap is a very straightforward process, but what we want out of a bottle opener can vary widely because it also satisfies other purposes. Each of the designers met the design brief and were very close in score. Each could be further optimised, but the debate over whose design is the best will continue – likely over a beverage, which is a good thing.

What has been learned?

Our data-driven approach ensured a fully functional design that suits multiple purposes for the lowest cost. The initial discussion on what problem was to be solved was worth the investment in time. Requirements are not meant to constrain design, but ensure the best possible outcome and a methodical approach. Some key takeaways:

There are always multiple valid solutions

The results show that the function of opening a bottle can be achieved in a variety of different concepts, taking many shapes but this exercise was more than just meeting a strength requirement.

Powder of choice

Titanium was the preferred material over aluminium or steel for strength to reduce mass and, therefore, build time.

Lattices never eventuated

The original discussion around lattices never eventuated. Once the fatigue and build time considerations of using contouring parameters were considered, it was faster and cheaper to go solid. In this case, the lattice is really more for aesthetics and can add perceived value, but, in reality, it does not add functional performance and it does add cost. The old adage 'no cost for complexity' is not entirely true.

Minimising environmental impact

All of the approaches took in a minimal environmental impact. There is a lot more that could be done here, but, hopefully, lasting forever so that

"Once the fatigue and build time considerations of using contouring parameters were considered, it was faster and cheaper to go solid. In this case, the lattice is really more for aesthetics and can add perceived value, but, in reality, it does not add functional performance and it does add cost. The old adage 'no cost for complexity' is not entirely true."

it does not end up in a landfill is a start. Using a material that is almost infinitely recyclable is yet another step.

Machine choice highlights best practice

AM machine choice, orientation, and build nesting can all be optimised for the desired outcome. There are several factors here and this question generated interesting insight into how a service bureau operates:

- Choose the least-utilised machine available and set it to build openers at whatever speed is feasible
- Select the machine that produces the target number in one build
- Choose the machine with the shortest build time for the fastest turnaround right before the tradeshow
- Choose the machine that slowly churns away overnight or at the weekend, because no one is there to turn it over anyway
- Stacking vertically or horizontally depending on the goal of more openers (vertically) or shorter build time (horizontally)

Where to from here?

Now the testing begins. It will be a hard task to swallow, but everyone must lever their enthusiasm for the betterment of the industry. Opening bottle after bottle to explore the fatigue implications and whether the design approach of 'infinite life' worked. Of course, the contents of those bottles shouldn't be wasted; that would be inconsistent with our sustainability ethic.

By studying the problem and producing a set of requirements with a weighting ultimately paid dividends. It was clear to the designers what must be done and what value additional functionality might have. Taking a methodical approach to assess each design made the exercise less subjective, but the combination of efforts was provided to work as all three designs met all the requirements. Designs not driven by requirements will increase the risk of an incomplete solution. Hopefully, the role of Design for AM within the family of Design for Manufacturing has been demonstrated. Additionally, within Design for AM, the roles MfAM and DfAM play in cost and producibility have also been demonstrated.

Authors

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www.apworks.de

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Constellium Aheadd® CP1 alloy: Breakthrough productivity in PBF-LB Additive Manufacturing

A collaborative study between Constellium SE, a global leader in aluminium materials headquartered in Paris, France, and a leading German AM research institute, has developed a new alloy which paves the way for cost-effective and high-performance AM components in series production. In this article, Constellium's Dr Bechir Chehab and Syam Unnikrishnan present the company's Aheadd® CP1 alloy, revealing cutting-edge productivity, very good mechanical properties, and the possibility to reduce Laser Beam Powder Bed Fusion (PBF-LB) processing costs by up to 65%.

Day by day, the AM processing of aluminium components by Laser Beam Powder Bed Fusion (PBF-LB) is being incrementally improved; however, so far, the current state-of-the-art solutions have resulted in only limited interest from OEMs because of technical and commercial challenges. One of the factors behind these challenges is that the majority of the popular PBF-LB aluminium alloy systems are modified versions of conventional alloys and, as such, they are not well suited to the Powder Bed Fusion process.

These difficulties create significant limitations to scale up the production process and to qualify AM aluminium components for series production. Realising the bottlenecks and, as a response to customers' requests to develop suitable alloys for PBF-LB, Constellium has introduced a novel aluminium alloy, Aheadd® CP1, and a recent study highlights its potential for new AM designs and component-level cost reduction.

Study outline

During the initial phase of the study, Constellium set challenging targets, in terms of productivity, density, and mechanical properties. Work with Aheadd CP1 had previously shown glimpses of high productivity combined with better properties in low and medium power PBF-LB machines, but the layer thickness had been limited to 60 µm.

This new study was performed using an industrial scale SLM Solutions PBF-LB machine equipped with 1 kW laser power using inert

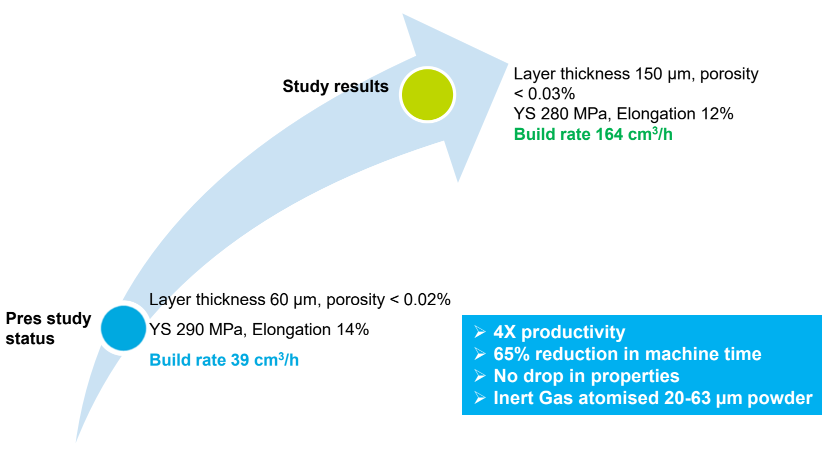

Fig. 1 The study provides an opportunity to develop cost-efficient and high-performance aluminium Laser Beam Powder Bed Fusion (LBF-PB) components in series production

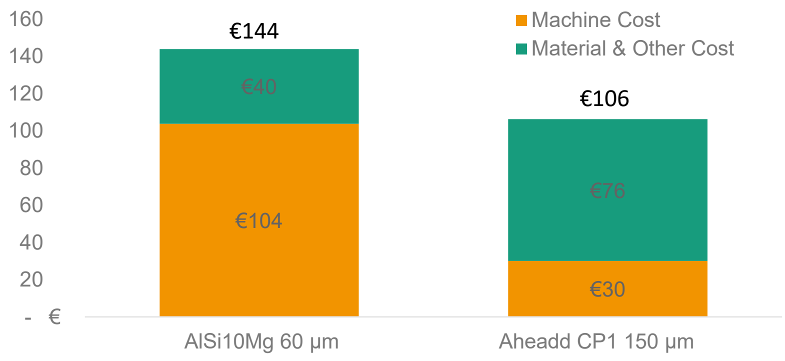

Fig. 2 Built component cost assessment (Data courtesy – Fraunhofer IAPT)

gas atomised Aheadd CP1 powder (20-63 µm). The project team developed the build process to spread the powder at 100,120, and 150 µm layer thicknesses and successfully produced high-quality specimens in all three layers without compromising the alloy's mechanical properties.

The processing window proved to be very wide and robust for the three different layer thicknesses, and the build rate potential ranged between 110 cm³/h and 164 cm³/h. For PBF-LB aluminium alloys, such build speeds and performance are unusual, with most aluminium alloy powders exhibiting difficulties above a 90 µm layer thickness. This high productivity opens the possibility for customers to significantly reduce the cost of AM components and target new applications by utilising the combination of excellent alloy performance and processability.

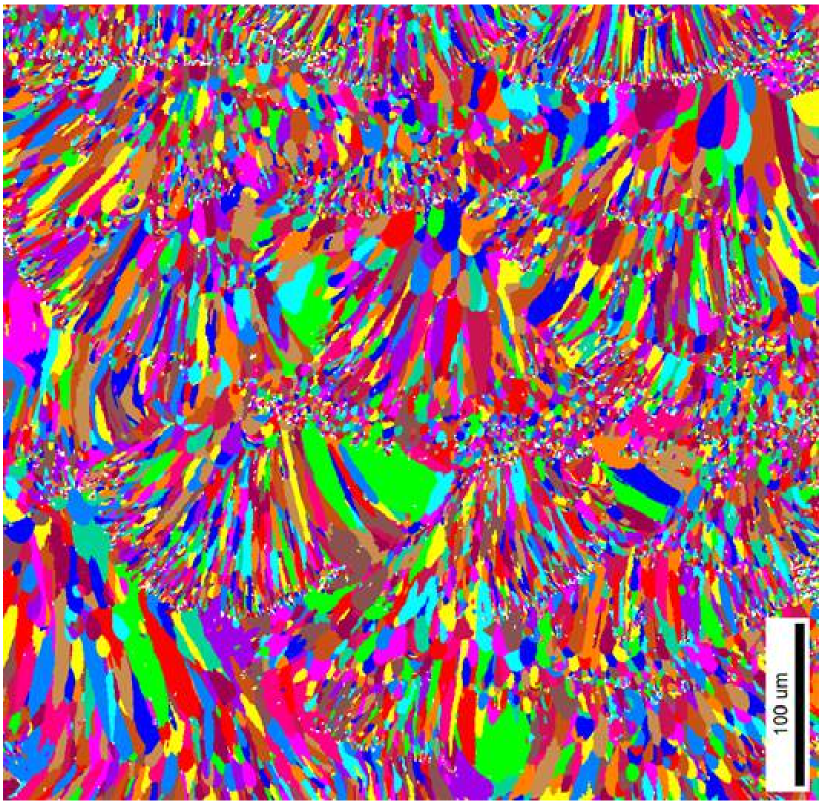

Fig. 3 Aheadd CP1 bimodal grain structure: fine equiaxed & microcolumnar grains

In addition to the productivity study, the project team developed an initial set of parameters to assess the surface roughness properties of the alloy (Fig. 1). Contrary to the behaviour of standard PBF-LB aluminium alloys, surface roughness did not vary drastically from the vertical surface to the horizontal one. The Ra value ranged between 22-32 µm for the increased layer thickness of the 120 µm build. Such a minor difference in Ra value variation is expected to provide an advantage when designing components with improved fatigue performance.

The heat treatment of the Aheadd CP1 alloy is very simple; no quenching or solution treatment is required to achieve homogenous mechanical properties, thereby minimising complex post-processing. This is attractive for AM users who require consistently tight parts tolerance.

In addition to the cost reduction potential of the material, users are able to push a component's performance boundaries such as increased load-bearing capability, good corrosion performance, and the possibility to develop large complex geometries without quality issues, thanks to the high ductility and low residual stress of the component in the as-built condition.

For many applications, anodising is vital to ensure good durability for a component's service life. Aheadd CP1's behaviour was found to be excellent during the industrial anodising processes. Although there is an ample supply of high-quality AlSi10Mg powder, the inability to anodise silicon-containing alloys is inhibiting the qualification of critical components in service. Aheadd CP1, in that regard, offers a promising solution to replace AlSi10Mg-based AM components and allow benefits both in terms of cost and performance advantages.

Fig. 2 shows a cost analysis based on a representative use case. The costs were calculated based on a part with printed volume of 145 cm³ with dimensions of 240 x 90 x 87 mm³. The cost assessment presented here was based on a full build of twenty-eight

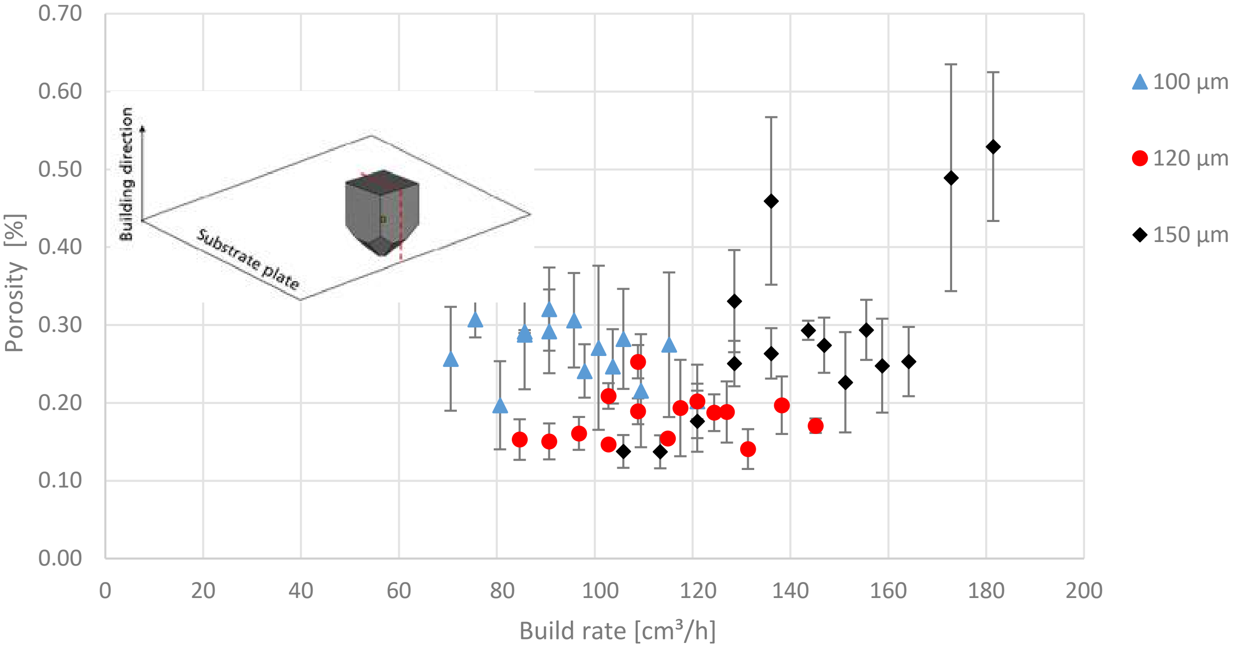

Fig. 4 Porosity of the cross-sections of the density cubes generated by 45 parameter combinations (3 different layer thicknesses: 100 µm, 120 µm and 150 µm) and their build rate (Data courtesy – Fraunhofer IAPT)

parts. Though the initial material cost for the alloy under investigation is higher than AlSi10Mg, the significant drop in machine costs per part by 70% still leads to a component cost reduction potential of > 25%.

Constellium's alloy design approach

Constellium has more than 100 years of experience in the development of high-performance aluminium alloys for challenging applications. The company recognised early in its exploration of AM technology that deriving solutions from conventional alloy systems was not the right strategy, and an 'out-of-the-box' design approach was adopted instead.

A novel alloy for the PBF-LB market is, however, only viable when powder production can be scaled up, the build processes are straightforward, and post-processing is kept to a minimum. In addition, the alloy must be able to cover the widest possible range of applications areas and, most importantly, be able to produce components cost effectively.

In the development of Aheadd CP1, the company worked with leading AM adopters and industrial end-users in order to understand the most important and 'non-negotiable' performance requirements.

Process qualification and parameter optimisation for new levels of productivity

Theoretical build speed is defined through the molten volume per time unit. It is expressed by the formula $v_s \cdot h_s \cdot t_s$, where v_s is the exposure speed, h_s is the hatch distance and t_s is the layer thickness. Hence, this characteristic value is only dependent on the process parameters. This allows the comparison of processes themselves, with no regard to individual machine configurations.

On the other hand, the productivity is usually defined as the efficiency of the production of goods; the time efficiency of a manufacturing process is, therefore, measured by the manufacturing time. The PBF-LB process is a three-step process that consists of recoating, exposure and substrate plate movement. These three steps repeat in such order until the part is generated. The build rate controls the exposure time, and the layer thickness controls the number of the layers, hence, both the total recoating time and the total exposure time. Both parameters play a role in the final manufacturing duration. For example, 150 µm layer thickness reduces the recoating time by 33% in comparison to 100 µm layer thickness.

In order to find the process window limits, the project team designed a process parameter development with 45 parameter combinations at three-layer thickness levels: 100, 120 and 150 µm. To investigate the resulting density of each parameter, density cubes of 10 x 10 x 10 mm^3 were generated in three different build jobs. For each parameter combination, three cubes were generated, totalling 135 cubic specimens.

The cross-section perpendicular to the substrate plate was ground, polished and the density was measured by light microscopy. The average porosities of the cubes are plotted against build speed rate in Fig. 4.

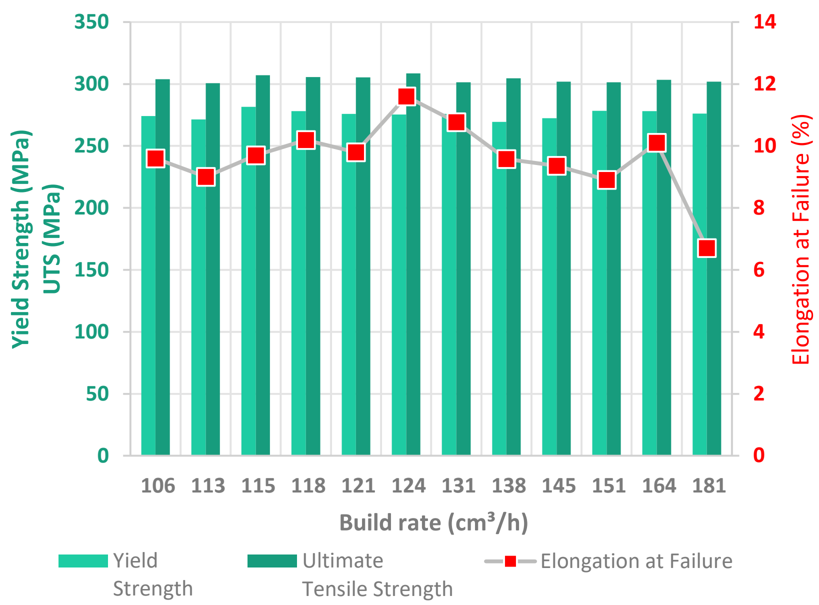

Fig. 5 Mechanical properties of Aheadd CP1 for different parameter combinations at build-up rates from 106 cm^3/h to 181 cm^3/h. Mechanical properties show a nearly constant behaviour for build-up rates until 181 cm^3/h where lack-fusion pores were noticed (Data courtesy Fraunhofer IAPT)

37 out of 45 parameter combinations could generate cubes with relative densities higher than 99.7% (porosity < 0.3%); 17 out of 45 parameter combinations were able to generate relative densities higher than 99.8% (porosity <0.2%).

The defects in almost all cubes were gas pores; lack of fusion defects were only identified when processing with build speed higher than 165 cm^3/h. A wide process window for Aheadd CP1 alloy could therefore be identified when using parameter sets optimised for high productivity.

To obtain the static mechanical properties of the material, flat tensile test specimens according to DIN 50125 were generated with the best parameter combinations from the density cube experiments. After the build, the specimens were removed from the substrate plate and sliced to the final shape by wire electrical discharge machining (EDM). The outer contours of the specimens were not machined and were kept in the as-built condition. The specimens were then heat treated at 400°C for 4 hours at Constellium before being tested. Considering all investigated parameter combinations, yield strength (YS) is in the range of 270-280 MPa, ultimate tensile strength (UTS) is in the range of 300-310 MPa, while elongation (EL) reaches 9-11%.

Fig. 5 shows the averages of the mechanical properties YS, UTS and Elongation at Failure for the Aheadd CP1 alloy for selected parameter combinations ranging from a build rate of 106 cm^3/h to 181 cm^3/h. It can be noted that, across the investigated build-up rates, YS and UTS do not depend on the process parameter combinations and are kept constant at high levels.

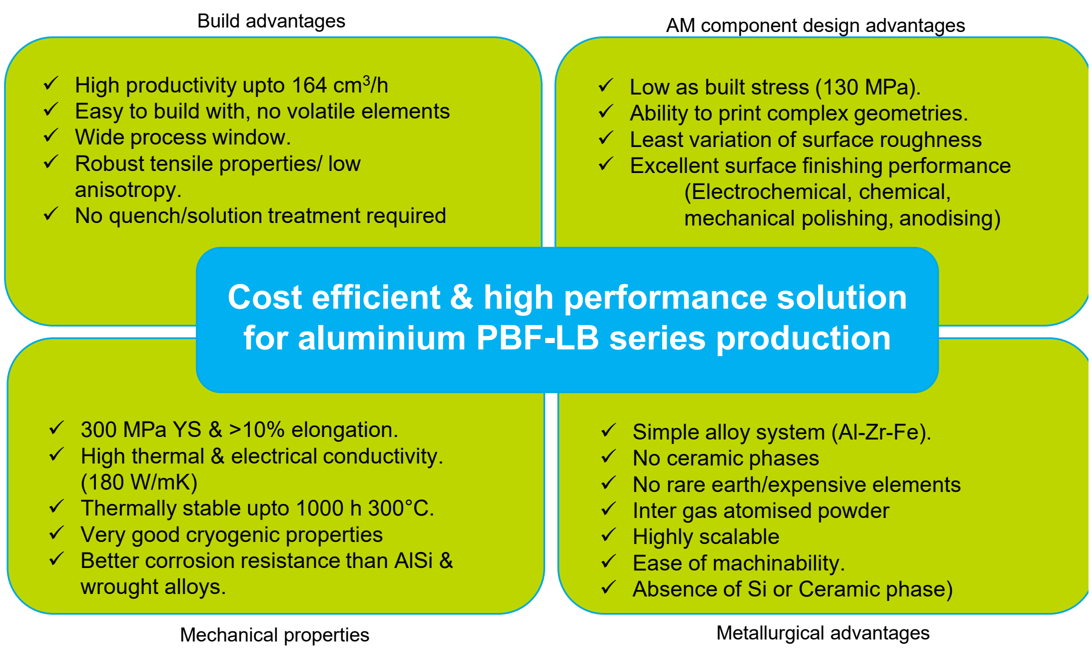

Fig. 6 Aheadd CP1: An alloy designed for the LBF-PB process

For build rates between 106 cm³/h and 164 cm³/h, the Elongation at Failure remains at a high level around 10%, with only slight variation. This is very likely to be a result of the good as built-condition of the tensile test specimen contour. The authors expect this variation to vanish, after surface-related process parameters, such as contour scans, are developed. The elongation at failure drops significantly at 181 cm³/h from approx. 10% to 6.7%. This decrease was expected, and can be explained by the occurrence of lack-of-fusion porosity, which was observed for parameter combinations with a build-up rate higher than 165 cm³/h.

Future work

As the mechanical properties from the tensile tests showed very promising results, especially for build-up rates that are more than four-fold higher than those usually used for AlSi10Mg, the next steps will be to refine surface-related process parameters as well as to test the fatigue behaviour for the as-built condition as well as in the machined condition.

Notwithstanding the high layer thicknesses of 100-150 µm that were considered in this study, initial results for surface roughness show promising values, allowing the project team to assume that surface roughness in the as-built condition of Ra<15 µm will be achieved within the ongoing optimisation process.

The entire development was performed on an industrial platform and the product has achieved a high maturity level. Constellium will be glad to help customers, who would like to benefit from cost-efficient and high-performance AM aluminium components and to explore new use cases that can lead to future series production of aluminium PBF-LB components.

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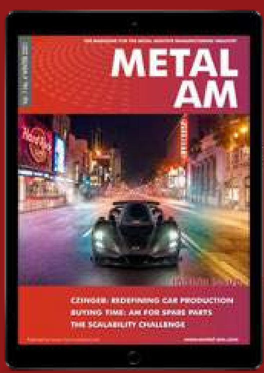
From the archives...

Winter 2021

The *Metal Additive Manufacturing* archive gives free access to all our back issues, offering the most comprehensive insight into the world of metal AM.

Our Winter 2021 issue includes the following articles and technical reviews:

- Metal AM in automotive: How the Czinger 21C is redefining next-generation car manufacturing
- Buying time with digital spare parts: Opportunities for metal Additive Manufacturing
- Burloak and the AM scalability challenge: A contract manufacturer's perspective on the shift to volume production
- Binder Jetting and beyond: Insights from Fraunhofer IFAM's second workshop on sinter-based Additive Manufacturing
- The inestimable value of AI: How Machine Learning can help AM project teams achieve their goals and beyond
- The need for global standardisation: Takeaways from the Standards Forum at Formnext 2021
- Laser Beam Powder Bed Fusion: Process developments and numerical simulation



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Metal powder characterisation: standards and test methods for consistent quality in AM

While Additive Manufacturing uses some powder characterisation methods similar to those used in conventional metal powder technologies, it is necessary to define additional properties critical for repeatable, reliable AM. ASTM International's Dr Alexander Liu, Head of Additive Manufacturing Programs – Asia Region, Singapore, and Dr Rafi Khalid, Sr Lead, Additive Manufacturing Programs Development, Singapore, outline the key metal powder characteristics for AM and their significance, as well as discuss the industrial test methods and standards AM part makers rely on to maintain consistent quality.

Powder is the most common feedstock for metal Additive Manufacturing, but, even before AM, metal powders were widely used for processes, such as 'press and sinter' Powder Metallurgy (PM), Metal Injection Moulding (MIM), and Hot Isostatic Pressing (HIP), as well as a range of uses which do not fall under the umbrella of PM. The Powder Metallurgy industries commonly characterise metal powders by their chemical, physical, and rheological (i.e., flow) properties. These powder characteristics have a strong effect on the quality and performance of the parts produced. Regardless of the application, industries need relevant and up-to-date powder characterisation methods and standards to maintain a consistent quality of manufacturing.

AM uses methods to characterise powder that are similar to traditional metal manufacturing techniques. However, due to the nature of AM processes, additional properties need to be defined. Important factors are the flow, shape, morphology, particle size distribution (PSD), chemistry, and packing density of the powder. These properties are critical for consistent, repeatable, and reliable AM. Powders behave differently, depending on the environment and process parameters they are exposed to.

For instance, the minimum layer thickness for Powder Bed Fusion (PBF) is a function of the powder particle size. To additively manufacture a layer of 20 μm versus 100 μm in thickness, the powder particle size can be different. This is why it is essential to define the requirements for powder properties in the form of powder specifications. For metal AM processes, powder

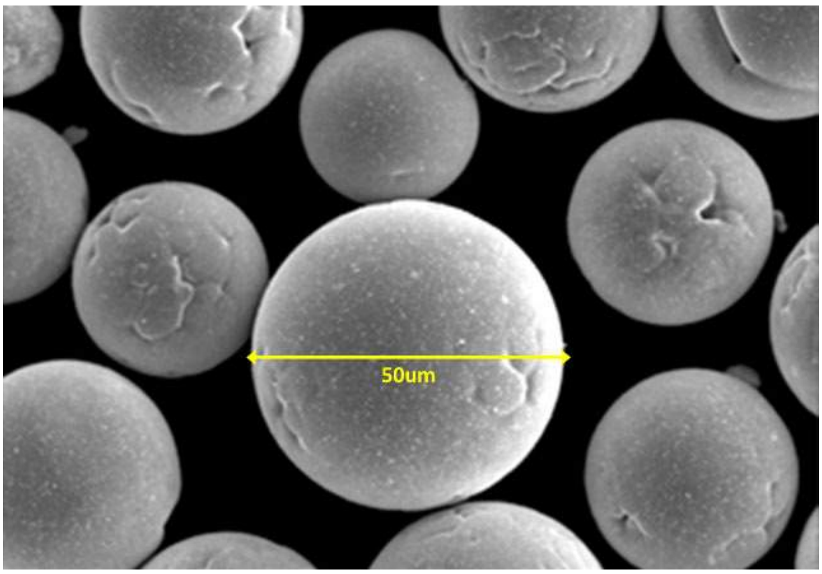

Fig. 1 A SEM image of gas atomised steel powder (Courtesy Temasek Polytechnic, Singapore)

Characteristics	Effects on AM	Common detection methods
Chemical composition	Differences in chemical composition will influence the final part properties. Compliance with existing material standards pertaining to different industrial applications is necessary	Inductively coupled plasma, optical emission spectroscopy, X-ray fluorescence
Particle Size Distribution	The minimum layer thickness that can be built in Additive Manufacturing is a function of powder particle size. The range of PSD influences the energy requirement and the packing bed density	Laser diffraction and sieve analysis
Flowability	Influences the homogeneous distribution of powder in the powder bed. Flowability will be poor for powder batches containing a large proportion of smaller particles less than 6 µm (0.0002 in)	Hall flowmeter, Carney flow-meter, powder rheometry
Density	Effective packing of powder is required to ensure minimum porosity in the final part. Packing density has a significant effect on the thermal conductivity of the powder bed	Hall flowmeter, Carney flow-meter, Scott volumeter, and gas pycnometer
Powder morphology	Influences homogeneous distribution of powder and the packing density. Powders with spherical shapes that spread easily in the powder bed are required for AM	Scanning Electron Microscopy (SEM)
Microstructure	Important to understand the grain morphology of the powder and to correlate it with microstructural characteristics of the final part	Optical microscopy or SEM
Thermal conductivity	An important thermo-physical property of the metal powder, which affects the consolidation behaviour of powder	Guarded hot plate method

Table 1 An overview of key powder characteristics and a summary of their significance in the AM process

quality will always be one of the most critical factors to ensure good part production.

The process used to manufacture the metal powders directly influences the powder characteristics. The majority of AM powders are produced by gas atomisation and plasma atomisation. The powder properties depend on the atomisation conditions, powder handling, storage, and shipping. Tight controls and traceability are required to ensure quality standards are met. These additional measures can lead to additional costs.

While transporting powder from the production facility to the customer or manufacturing location, ambient temperature and humidity can affect the characteristics of the powder, so it must remain dry and free from contamination during transportation and storage. This is why the AM industry needs a way to ensure the quality of powder is maintained throughout the supply chain. It is good practice to test the powder at the production and manufacturing facility.

Different metal powder characteristics and their significance in the AM process

Table 1 describes the key characteristics that should be assessed before metal powder is used for PBF or Directed Energy Deposition (DED). Each characteristic can influence the process and impacts the final properties of the part.

Powder characteristics are interdependent with other properties. For example, flowability is dependent on a combination of properties; spherical shaped and large particles tend to improve flow. They are characterised by powder morphology and PSD respectively. Before performing powder characterisation, it is best practice to:

- Ensure the powder sample is obtained from a properly stored condition, including maintaining required humidity levels and free of contamination
- Follow a powder sampling practice such as ASTM B215-10, practice B
- Document the details such as supplier information, date of first opening the container, and batch/lot number
- Identify the applications and the compliance requirements (such as ASTM F1472 / ISO 5832-3 for surgical implants)

ASTM B212 Apparent density of free-flowing metal powders using Hall Flowmeter Funnel	ASTM B213 Flow rate of metal powders using Hall Flowmeter Funnel	ASTM B214 Sieve analysis of metal powders	ASTM B215 Sampling metal powders	ASTM B417 Apparent density non-free flowing metal powders using Carney Funnel	ASTM B527 Tap density of metallic powders and compounds
ASTM B822 Particle size distribution of metal powders and related compounds by light scattering	ASTM B855 Volumetric flow rate of metal powders using Arnold Meter and Hall Flowmeter Funnel	ASTM B923 Metal powder skeletal density by Helium or Nitrogen Pycnometry	ASTM B964 Flow rate of metal powders using Arnold Meter and Hall Flowmeter Funnel	ASTM E1019 Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys	ASTM E1409 Oxygen and nitrogen in titanium and titanium alloys by inert gas fusion
ASTM E1447 Hydrogen in titanium and titanium alloys by inert gas fusion thermal conductivity/infrared detection	ASTM E1834 Nickel alloys by graphite furnace atomic absorption spectrometry	ASTM E1941 Carbon in refractory and reactive metals and their alloys by combustion analysis	ASTM E2465 Ni-based alloys by Wavelength Dispersive X-Ray Fluorescence Spectrometry	ASTM E2954 Nickel alloys by Inductively Coupled Plasma Atomic Emission Spectrometry	ASTM E2823 Nickel alloys by Inductively Coupled Plasma Mass Spectrometry
ASTM E3047 Nickel alloys by Spark Atomic Emission Spectrometry	ASTM E3061 Aluminum and aluminum Alloys by inductively coupled plasma atomic emission spectrometry	ISO 4497 Metal powders, dry sieving	ISO 13320 Particle size – laser diffraction	ISO 13322-1/ 13322-2 Particle size – image analysis	ISO 3923-1 Metallic powders, Funnel Method

Fig. 2 Standards in the ASTM Additive Manufacturing Powder Metallurgy Proficiency Testing Program (Courtesy of ASTM International)

Standards applicable for powders

Standards development organisations are working to publish test methods for powder characterisation. Standards are essential to ensure quality and consistency of powders. ASTM International and ISO have both published several standards that can be used to characterise the properties described in Table 1. These tests are usually done by the powder producer using in-house and/or outsourced equipment. In most cases, testing requires a combination of both to report the characteristics of the powder.

To provide quality assurance to customers, a certificate of compliance is commonly provided with the delivery of the powder. Often, users rely on these test results to match their powder specifications. The specifications of the powder depend on the qualification and application requirements of the user, including feedstock purchase and use specifications. The purchase specification describes the required properties of the powder, while the feedstock use specifications define the acceptance criteria of the powder properties intended for use within the selected AM process. To enhance quality assurance and meet regulatory requirements, users may also perform tests on the powders.

Consistent powder characteristics are crucial to ensure repeatable manufacturing of metal AM parts. One of the key challenges in powder testing is maintaining consistency in the test results across different facilities. Despite well-defined methodologies for testing metal powder, the results will usually not be the same when tested by different organisations – or even technicians within the same organisation. This happens in practice even when the same test method standard is being used for the same batch of powder.

Variations in test results occur primarily because of the conditions in the test lab. In the test lab, the powder is exposed to many variables that can skew the results. This could include environmental conditions, improper material handling practices, untrained operators, and a lack of documented procedures. This is why it is in the end users' interest that the powder has been tested by a qualified lab. These types of labs have demonstrated testing capabilities according to the applicable standards published by ASTM International and/or ISO.

One approach to ensure the reliability of the powder characterisation results is to generate data describing the performance of the powder testing facility. The ASTM Additive Manufacturing Powder Metallurgy Proficiency Testing Program (AMPM PTP) is designed to address this. It is used as a statistical quality control tool to enable participating laboratories to assess their performance when testing powder. AMPM PTP is supported by long-standing relationships with ASTM International committees B09 on metal powders and metal powder products and F42 on AM. The programme helps monitor a lab's strengths and weaknesses and, furthermore, helps improve and maintain a high level of performance

Lab code	Undried (g/cm³)	Dried (g/cm³)
0002	4.25	4.34
0003	4.25	4.25
0004	4.25	4.35
0005	4.23	4.25
0008	4.45	4.28
0009	4.29	4.37
0010		4.15
0011	4.22	4.26
0012	4.32	4.30
0013	4.25	4.22
0015	4.25	4.25
0016	4.25	4.30
0019	4.22	4.25
0022		4.27

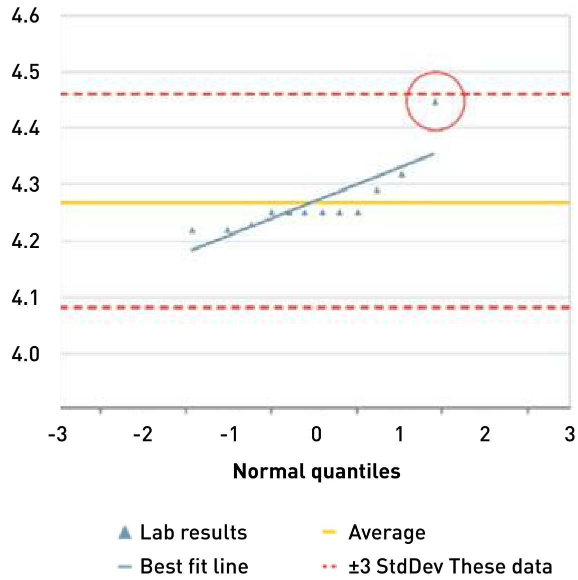

Fig. 3 An example of statistical analysis on ASTM B212 from AMPM PTP participants (Courtesy ASTM International)

using test methods from ASTM to compare labs. This programme also helps labs meet accreditation requirements.

AMPM PTP is into its fourth year and has over fifty-three participating labs from more than fourteen countries. The programme conducts cycles in April and October each year using different alloys, including titanium, nickel, steel and aluminium. Each participating lab receives a comprehensive report on the statistics of test results to understand the characteristics of powders. This report can be used to satisfy accreditation requirements and demonstrate a lab's capabilities for industries beyond AM.

It is necessary to understand both the fundamentals of a powder's behaviour and the AM process in order to describe the relevant test methods and identify gaps in standards. AMPM PTP also benefits standards development committees by continuously improving and revising existing standards. The programme also facilitates new specifications and methods for metal powders specifically for AM. Fig. 2 shows the standards used in the AMPM PTP.

Participants stand to improve and maintain a high level of performance using ASTM test methods when compared with other labs from around the world. The ASTM B212 Apparent Density Using Hall Flowmeter Funnel standard is used as an example of how a participant can benefit from AMPM PTP (Fig 3). The ASTM D7915-14 standard method was used for identifying outliers. As shown, the average and standard deviation are plotted based on the results provided by participants. One result was near the upper limit while still within the acceptance criteria. Even though the results were within the acceptable three standard deviations range, this lab should improve its testing capability for ASTM B212.

Additional standard test methods specific to AM, such as powder spreadability, are under development as of the end of February 2022. These new standards will be inducted into AMPM PTP when they are published. Manufacturing companies, equipment vendors, university research labs and government agencies are encouraged to participate in this programme to improve their proficiency in metal powder characterisation.

Conclusion

Defining a specific set of requirements for powder properties is the first step in ensuring quality powder for AM. It is important to adopt industry-relevant and current powder characterisation methods and standards to determine these properties. Having the powders tested by a qualified and certified laboratory is equally important to ensure the data is reliable. For AM, powder quality remains the basis for process repeatability and reliability and the production of quality parts.

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Euro PM2021: Advances in the processing of nickel alloy 718 and molybdenum by Laser Beam Powder Bed Fusion

A technical session in the programme of the virtual Euro PM2021 conference, organised by the European Powder Metallurgy Association (EPMA) and held October 18-22, 2021, focused on issues related to the processing of nickel-base alloys and refractory metals by Laser Beam Powder Bed Fusion (PBF-LB) Additive Manufacturing. Dr David Whittaker reviews four papers that address microstructure control, lattice optimisation and chemical post-processing parameters for IN718, and the AM of molybdenum.

Microstructure control of additively manufactured IN718 by PBF-LB

The first of the reviewed papers considered strategies for the control of microstructure in IN718, additively manufactured by the Laser Beam Powder Bed Fusion (PBF-LB) process [1]. The paper was authored by L Lacoste, S Depinoy and C Colin (Mines ParisTech - PSL University, France) and A Sakly, S Lebel and B Vayre (AddUp, France).

In PBF-LB, the combination of a layer-by-layer manufacturing process with a high thermal gradient and solidification rate results in epitaxial growth through multiple layers. Mechanisms governing the variation of the microstructure have been investigated in order to produce isotropic part and, most importantly, to adapt the microstructures of AM parts to their applications in service.

Reported literature has identified four interlinked major levers that can lead to isotropic microstructures. The first of these levers consists of reducing thermal gradients to reach the columnar-equiaxed transition (CET). However, for the PBF-LB process, this is difficult – even impossible – to achieve through variations of primary parameters such as laser power and scanning speed.

The preheating temperature is the most effective parameter for decreasing thermal gradients in the PBF-LB and Electron Beam Powder Bed Fusion (PBF-EB) processes. Unfortunately, in the case of the PBF-LB process, preheating systems are not yet mature enough for industrial use.

A second lever is the aspect ratio of the melt pool, which can be modi-

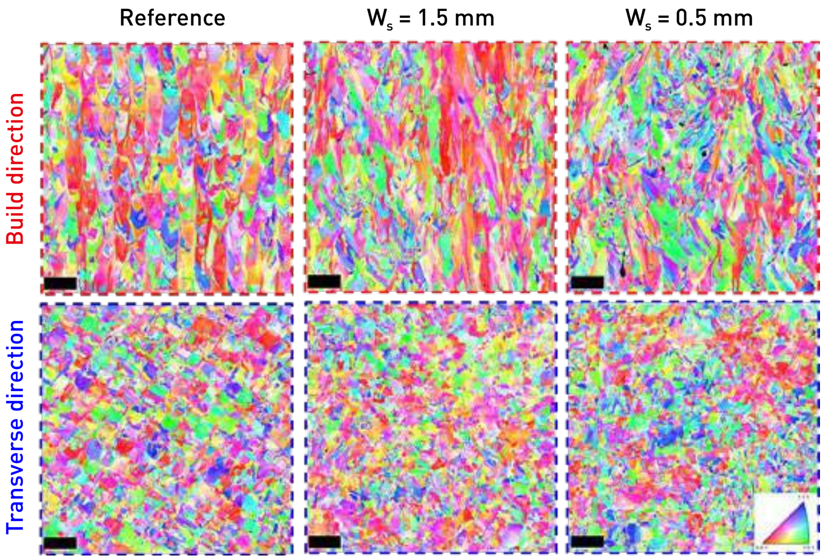

Fig. 1 IPF maps of Reference, W_s = 1.5 mm and W_s = 0.5 mm for build (red dashed line) and transverse (blue dashed line) directions. Black scale on the bottom of the maps indicates 100 µm [1]

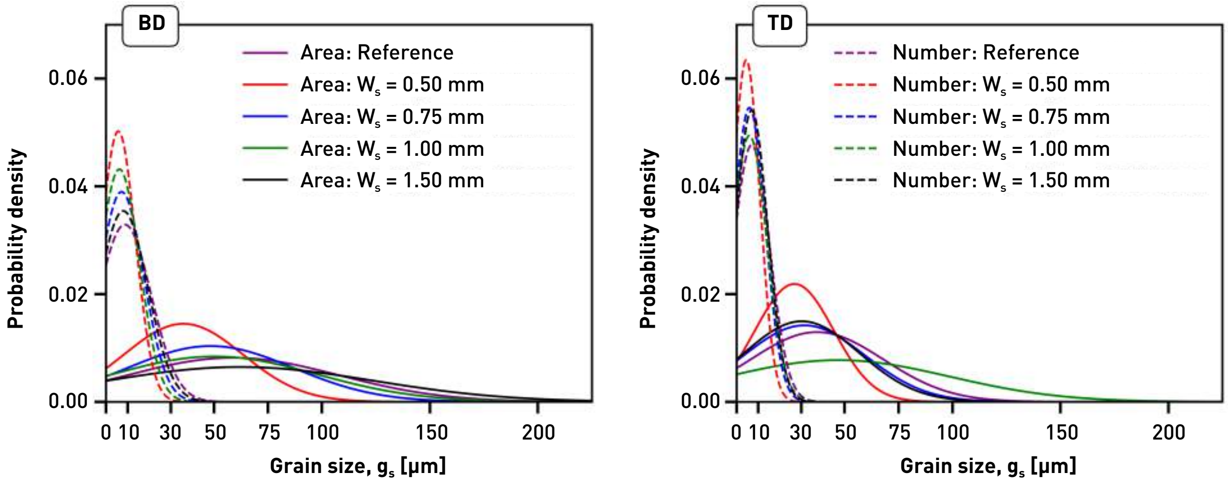

Fig. 2 Normal distribution of the grain size weighted by the number of grains (Number) and the area of grains (Area) for BD (left) and TD (right) at the DoE W_S values [1]

fied by standard PBF-LB parameters, by laser beam shaping or even by using a top-hat source instead of a Gaussian one. However, this requires the modification of the PBF-LB machine laser optical path, a rather complex operation.

More recently, some studies have focused on the addition of inoculants to the powder with significant results. The main drawback of this third lever is that any change in the chemical composition means a requalification process for industrial applications. The final lever is the inhibition of epitaxial growth. In layer-by-layer manufacturing, two types of epitaxial growth can be distinguished: transverse epitaxy, between two tracks side by side of the same layer, and axial epitaxy, between two tracks from one layer to another. The first epitaxy is mainly governed by the path of the laser beam and the overlap between two tracks and, therefore, by the hatch spacing. The second epitaxy is controlled by the axial dilution defined by the number of re-melted layers.

The reported study was aimed at investigating the impact of scanned length on epitaxy, in order to achieve an un-textured microstructure and a significant reduction in grain size.

10 x 10 x 12 mm^3 specimens were built from a gas atomised IN718 powder, with a particle size distribution D_{10} = 10 μm and D_{90} = 53 μm and an average size D_{50} = 30 μm. A FormUp 350 machine from AddUp, with a laser power P = 220 W, a scanning speed V_b = 2100 $mm.s^{-1}$ and a focused laser beam diameter ϕL = 70 μm, was used. The hatch spacing and the powder layer thickness were set at h_s = 55 μm and ΔZ = 40 μm, respectively.

Strip scanning strategies were developed in the AddUp Manager software. The variable of interest in this design of experiments was the strip width, W_s. Strip widths of 0.5 mm, 0.75 mm, 1.0 mm and 1.5 mm were used. The scanning was orthogonal to the bands, so W_s is the scanning distance for one single track. A staggered strip scanning strategy was applied to reduce the overall thermal gradient in the blocks.

Finally, an incremental rotation of 67° from one layer to another was applied to avoid preferential growth directions and thus reduce the axial epitaxy. A reference block with a standard bi-directional scanning and a rotation of 90° between two layers was also built.

Samples were cut along two mid-planes in the build direction (BD) and in the transverse direction (TD) (i.e., orthogonal and parallel to the build plate). After standard polishing, EBSD analyses were carried out; an analysed area of 0.85 x 0.85 mm^2 and a step of 0.5 μm were used. EBSD post-processing. as maps of inverse pole figures (IPF), grain aspect ratio (AR, min axis / max axis), grain size, texture analysis and the determination of the Taylor factor were achieved using the TSL OIM software package. IPF maps were computed with the <001> direction aligned with the build direction (BD).

Fig. 1 shows the IPF mapping along the BD and TD directions for the reference sample, the one with W_s = 1.5 mm and the one with W_s = 0.5 mm. The reference exhibited a classic microstructure with columnar grains spaced by a distance hs along BD, associated with a <001> texture. Square-based grains with a side of length hs were observed along TD. On the other hand, the wider strips (W_s = 1.5 mm) still had columnar grains with the <001> texture, but there was no regular basaltic pattern along BD and TD. The narrower strips (W_s = 0.5 mm) showed disorganised columnar grains of smaller size and no dominant crystallographic texture. Furthermore, decreasing W_s tended to change the grain morphology such that they became slightly less columnar.

Fig. 2 shows the number- and area-weighted grain size distributions as a function of W_s in both TD and BD directions, where the grain size, g_s, is taken as the equivalent diameter. The number-weighted distribution is representative of the number of nucleation events that took place during the build, while the area-weighted distribution is more representative of the material at the macroscopic scale.

Decreasing the strip width clearly leads to a less scattered grain size distribution and an overall smaller grain size regardless of the weight and of the direction of interest. Along BD, area- and number-weighted maximum grain size increased from 120 µm and 30 µm to 220 µm and 45 µm, when W_s was increased from 0.5 mm to 1.5 mm. A similar trend, albeit to a lesser extent, was observed in TD: a scanning width of 0.5 mm led to area- and number-weighted maximal grain sizes of 85 µm and 25 µm, respectively, and of 125 µm and 35 µm for a scanning width of 1.5 mm. It should be emphasised that the differences between BD and TD were related to the fact that the average aspect ratio is not fixed.

The texture index TI (i.e., the 16th order of the harmonic expansion) and the mean Taylor factor ⟨M⟩ were calculated to assess the effect of the scanning width on the crystallographic texture. The Taylor factor is a generalisation of Schmid's law for polycrystalline materials and is equal to 3.06 when texture is random. A lower Taylor factor means that the material deforms more easily due to the preferential alignment of slip systems. The grain density g_d (in mm^{-2}), i.e., the number of grains per unit area, and the number- and area-weighted mean grain size, $\langle g_s \rangle$ in µm, were used to summarise the results shown in Figs. 1 and 2, with reference to the fineness of the microstructure. Fig. 3 shows the evolution of these four parameters as a function of strip width, W_s.

From Fig. 3, along BD, it can be seen that an increase in W_s induced higher values of $\langle g_s \rangle$ and TI. On the other hand, a decrease in the parameters g_d and ⟨M⟩ were observed with increasing W_s. In fact, the larger the grains, the lower was the grain density. This same tendency occurred between the texture index and the Taylor factor. It is also interesting to note that the measured quantities of TI and ⟨M⟩ for W_s = 0.5 mm were very close in the two directions BD and TD and tended towards isotropic values (1 and 3.06, respectively). Indeed, the relative differences between BD and TD for these quantities were 1.50% and 0.01 %, respectively, so that it could be safely assumed that there was no textural anisotropy in the thin strip sample, W_s = 0.5 mm.

In light of these results, thin strip strategies coupled with a 67° rotation between layers appears to be a promising approach to constructing more isotropic as-manufactured microstructures compared to conventional strategies.

Fig. 4 shows the appearance of new grains by plotting Δg_d as a

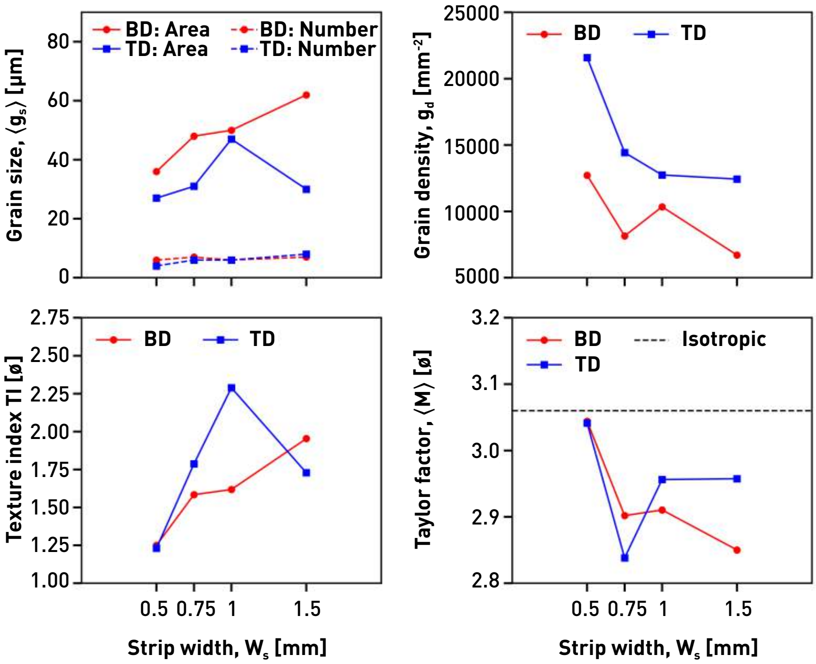

Fig. 3 Plots of the average grains size, $\langle g_s \rangle$ (top left), the grains density, g_d, (top right), the texture index, TI, (bottom left) and the average Taylor factor, ⟨M⟩, (bottom right) as a function of W_s [1]

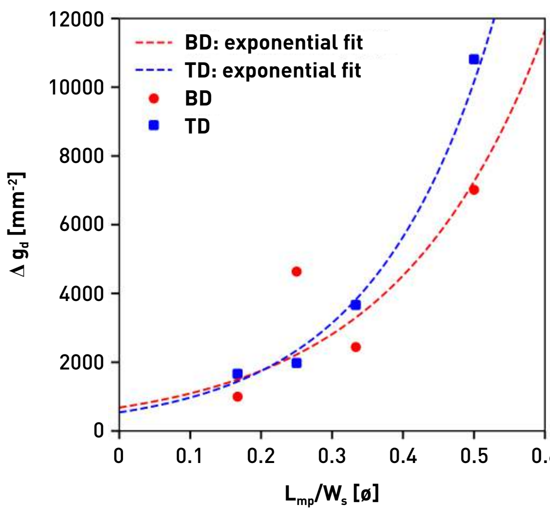

Fig. 4 Contribution of the strip strategy in terms of new grains, Δg_d, as a function of the normalised width strip, L_{mp} / W_s [1]

function of the melt pool length normalised by the strip width, W_s. From this figure, Δg_d seems to evolve exponentially with L_{mp} / W_s. The more the melt pool length normalised by the strip width tends towards 1 – i.e., $L_{mp} = W_s$ – the more new grains are formed. Indeed, there was a tenfold increase in new grains for the thinnest strip compared to the less fine one along TD and seven times more for BD. While the mechanisms leading to the increase in grain nucleation are not yet understood, the authors hypothesised that increasing L_{mp} / W_s above a given critical ratio (dependent on the scanning speed V_b) leads to the interaction of the laser beam with a larger volume that is not yet fully solidified from the previous track. This would have the effect of breaking the secondary arms of the dendrites during solidification, which would then act as heterogeneous nucleation sites ahead of the solidification front, effectively inhibiting transverse epitaxy.

As can be seen from Fig. 5, these results have paved the way for the production of isotropic parts and parts with different microstructural areas or microstructural gradient. Some interesting results require further study. In order to have a better understanding of the phenomena that occur during the remelting of a melt pool that is not fully solidified, the numerical simulation of a melt pool in steady state and in a transient regime can be of great help.

Finally, it is necessary to consider the scanning time for the entire part. These narrow strip strategies have the drawback of having a low build rate. The strategy at W_s = 500 μm requires a scan time three times longer than that for the reference strategy, dramatically increasing the production time. However, using the developed strategy at specific locations in a part to modify the microstructure and increase local mechanical properties is undoubtedly the best solution available to end-users.

Optimisation of PBF-LB Inconel 718 lattice structures for improving mechanical behaviour

The second paper remained with the same nickel superalloy, IN718, and addressed the optimisation of lattice structures built by PBF-LB for improving mechanical behaviour. This paper came from Shruti Banait, Xueze Jin and Teresa Perez- Prado (IMDEA Materials Institute, Spain) and Monica Campos (Universidad Carlos III de Madrid, Spain) [2].

Lattice structures are characterised by the repetition of a unit cell in three dimensions, thus consisting of a topologically ordered open-celled structure. The topology of strut-based lattice structures is inspired by crystalline lattice structures. Cubic, body centred cubic (bcc), face centred cubic (fcc), diamond, and octet-truss are some strut-based topologies.

Numerous researchers have reported the mechanical response of lattice structures in the literature, considering different cell topologies, such as bcc, fcc and their variants. Defects formed during the PBF-LB process may significantly affect mechanical response. These effects are more pronounced in shear loading than in compression loading. Lattice structures with larger strut diameters and smaller cell size exhibit higher modulus and thus better energy absorption properties. The overall mechanical response of the lattice structure is greatly influenced by parameters such as strut diameter, unit cell topology, cell size and relative density of the lattice.

Very few results have been reported in the literature on manufacturability studies for lattice structures in order to achieve optimal design and a negligible fraction of defects. Also, limited results have been reported, to date, on lattice structures fabricated with Ni-base superalloys, despite these alloys being compatible with PBF-LB technology. The work reported in this paper aimed to fill this gap by investigating the lattice structures fabricated with IN718 by PBF-LB technology. The work presented consisted of optimisation of bcc lattice strut diameter and

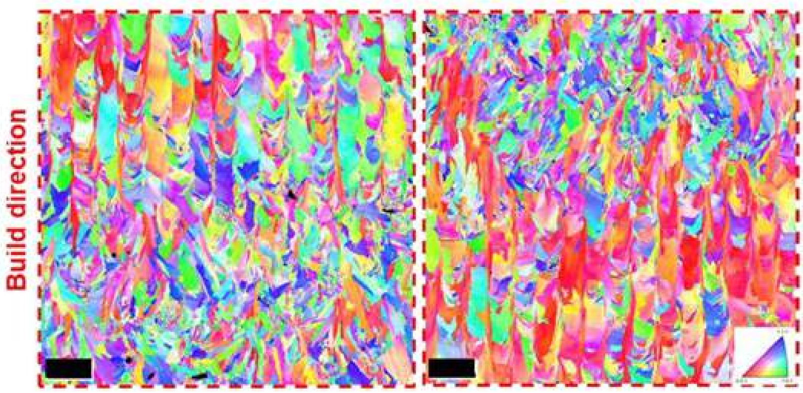

Fig. 5 IPF maps of controlled PBF-LB microstructure into the same sample, columnar grains with anisotropic crystallographic texture (top left & bottom right) and small grains with isotropic texture (bottom left & top right). Black scale on the bottom of the maps indicates 100 μm

Element	Fe	Ni	Al	B	C	Co	Cr	Mo	Nb+Ti	Ca	N
% wt.	Bal.	50.0-55.0	0.30-0.70	0.006 Max	0.02-0.08	1.0 Max	17.0-21.0	2.80-3.30	4.75-5.50	0.01 Max	0.03 Max

Table 1 Chemical composition of IN718 [2]

Fill power (W)	Border power (W)	Scan speed fill (mm/s)	Scan speed border (mm/s)	Hatch distance (μm)	Energy density fill (J/mm³)	Energy density border (J/mm³)
200	200	1166.7	333	90	63.49	444.89

Table 2 PBF-LB process parameters employed for strut diameter optimisation [2]

Fill power (W)	Border power (W)	Scan speed fill (mm/s)	Scan speed border (mm/s)	Hatch distance (μm)	Energy density fill (J/mm³)	Energy density border (J/mm³)	Upskin		Downskin	
							Border	Passes	Border	Passes
300	150	875	333	90	126.98	333.67	1	4	5	1
250	150	875	333	90	105.82	333.67	1	4	5	1
150	150	875	333	90	63.49	333.67	1	4	5	1
100	100	875	333	90	42.33	222.44	1	4	5	1
200	150	875	333	50	152.38	333.67	1	4	5	1
200	150	875	333	70	108.84	333.67	1	4	5	1
200	150	875	333	100	76.19	333.67	1	4	5	1
200	150	875	333	90	84.66	333.67	1	4	5	1
200	200	1166.7	333	90	63.49	444.89	1	4	5	1

Table 3 PBF-LB process parameters employed for porosity optimisation [2]

process parameters in order to obtain enhanced mechanical performance.

The powder used in the study had a particle size distribution ranging from 15 to 45 μm and the composition quoted in Table 1. The fabrication of the bcc lattices was carried out on a Renishaw AM 400 machine with a reduced build volume (RBV) of 78 mm x 78 mm x 55 mm. This system utilises a pulsating Yb fiber laser with a 400 W optical system, which gives out a focused beam of 70 μm diameter. The material used for the build plate was S 275 steel.

In order to optimise the strut diameter, three lattices were manufactured with 0.3, 0.4 and 0.5 mm strut diameters and 10 x 10 x 10 mm dimensions. The process parameters employed for the fabrication are indicated in Table 2. For each lattice, the support structure was detached from the base using an abrasive disc cutter.

To fix the optimal strut diameter for the lattice structure, the lattices shown in Figs. 6 (a), (b) and (c) were tested at room temperature compression. The resultant stress-strain curves are indicated in Fig. 6 (d). In the case of the samples with 0.5 mm and 0.4 mm strut diameters, the stress increased with strain monotonically, then remained basically constant during a plateau stage, before a final increase due to lattice collapse. The final sharp rise in stress indicates the interlocking of struts with no further room for compression. The stress-strain curve corresponding to the 0.3 mm strut diameter lattice showed no significant strength due to the breakage of struts immediately upon the application of the compressive stress.

Since strut diameters of 0.4 and 0.5 mm appear to endow the built lattices with a relatively similar mechanical behaviour, the choice between these two diameters was guided by previously published observations that

"In the case of the samples with 0.5 mm and 0.4 mm strut diameters, the stress increased with strain monotonically, then remained basically constant during a plateau stage, before a final increase due to lattice collapse. The final sharp rise in stress indicates the interlocking of struts with no further room for compression."

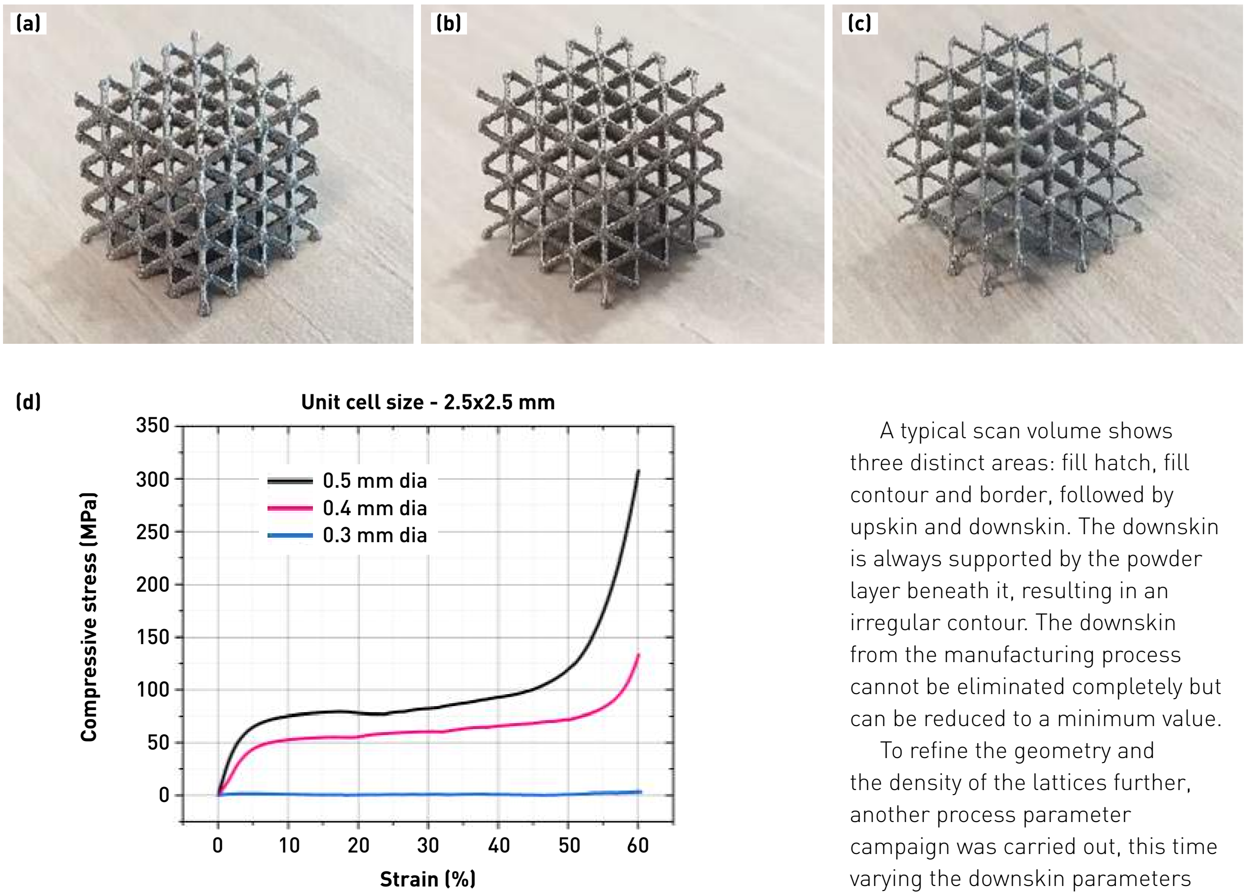

Fig. 6 Bcc lattices fabricated with process parameters from Table 2, having strut diameters (a) 0.5 mm, (b) 0.4 mm, (c) 0.3 mm and (d) stress-strain curve for room temperature compression [3]

reported an increase of the internal porosity of PBF-LB processed Ni superalloy lattices with increasing strut diameter. On the basis of this observation, the 0.4 mm strut diameter was selected as the optimal one. Hereafter, all the reported results correspond to lattices with a strut diameter of 0.4 mm.

After selecting 0.4 mm strut diameter as the optimal choice, the porosity in the lattice struts and nodes was optimised by designing an array of different levels of selected process parameters, as indicated in Table 3. Eight new combinations were considered, together with the one defined in Table 2.

A typical scan volume shows three distinct areas: fill hatch, fill contour and border, followed by upskin and downskin. The downskin is always supported by the powder layer beneath it, resulting in an irregular contour. The downskin from the manufacturing process cannot be eliminated completely but can be reduced to a minimum value.

To refine the geometry and the density of the lattices further, another process parameter campaign was carried out, this time varying the downskin parameters and number of volume borders. Laser power, border power, scan speed fill, scan speed border, hatch distance, energy density fill and energy density border were selected as combination number 4 from Table 3.

For both the process parameter optimistion campaigns, the bcc lattices were manufactured with a strut diameter of 0.4 mm and a dimension of 7.5 x 7.5 x 7.5 mm. For all the fabrications, a layer thickness of 30 µm and 'meander' scanning strategy was used.

With borders	1	2	3	4	5	6	7	8	9
Pore area	0.5232	0.3076	0.2315	0.0911	0.3569	0.1254	0.3263	0.265	0.1776
Lattice area	12.5237	10.9824	9.9158	8.7621	11.3635	6.4266	11.2174	9.4039	11.8104
% porosity	4.00	2.72	2.28	1.03	3.05	1.91	2.83	2.74	1.48
Without borders	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Pore area	0.2339	0.1609	0.0542	0.025	0.0938	0.0688	0.0819	0.0823	0.0826
Lattice area	10.3718	8.7745	7.7042	8.4457	9.2743	7.0996	8.7815	7.1846	7.3897
% porosity	2.20	1.80	0.70	0.30	1.00	0.96	0.92	1.13	1.10

Table 4 Percentage porosity calculated for porosity optimisation (respective lattice and pore areas are in mm^2) [2]

It was observed that the porosity is significant and the downskin is irregular. The lattices fabricated in accordance with the process parameters indicated in Table 3 were examined to calculate the % porosity. Table 4 shows the respective values of % porosity for these lattices.

It was observed that lattice cross sections with borders exhibit a superior geometrical form as compared to those without borders. It was also noted that sample number 4 from Table 4 exhibits the lowest porosity in the category of lattices with border. However, the downskin was still irregular. Therefore, another optimization campaign was followed for the purpose of improving the downskin and understanding the effect of borders for the process parameters of sample 4.

Table 5 shows the values of % porosity for the levels of parameters in the second porosity campaign. It was observed that the border is, indeed, important for maintaining the geometry of the lattice. Thus, scanning parameters were selected in order to better retain the geometrical shape of the downskin in the lattice and to achieve a significant low level of porosity.

With borders	1	2	3	4	5
Pore area	0.0053	0.008	0.009	0.05	0.0349
Lattice area	5.3355	5.4182	5.9354	7.7431	7.91
% porosity	0.10	0.15	0.15	0.64	0.44

Table 5 Percentage porosity calculated for porosity optimisation – 2, (respective lattice and pore areas are in mm^2) [2]

"It was observed that lattice cross sections with borders exhibit a superior geometrical form as compared to those without borders. It was also noted that sample number 4 from Table 4 exhibits the lowest porosity in the category of lattices with border. However, the downskin was still irregular."

Effect of chemical post-processing parameters on the surface roughness reduction and support removal of IN718 produced by PBF-LB

IN718 was again the material of choice in the third reported study. This paper came from David Pazos, Elixabete Espinosa and Belen Garcia-Blanco (CIDETEC, Spain) and Ione Golvano (Egile Mechanics, Spain) and considered the effect of chemical post-processing parameters in surface roughness reduction and support removal in parts produced by PBF-LB [3].

High surface roughness in AM parts arises from the layer-by-layer nature of the AM process, its manufacturing parameters and the orientation of the component. Defects during fabrication are generally represented by the staircase effect, due to the laser layers, partially melted powder particles, spatter or balling effects. Several methods have been developed in the past to reduce the surface roughness of as-built parts, with machining, shot peening, vibrating or (electro)chemical polishing being leading examples.

Support structures are necessary when manufacturing parts using PBF-LB. These structures have two main functions: firstly, to avoid part deformation attaching the work piece to the build platform and, secondly, to act as paths for dissipation of heat generated during manufacturing. Usually, supports are removed manually, by machining or by (electro) chemical treatments.

This reported study focused on chemical methods for removing support structures and decreasing surface roughness of IN718 PBF-LB parts.

The powders used in this study were gas atomised and had a particle size distribution in the range from 15 to 45 µm and the composition shown in Table 6. The build was carried out on a Renishaw AM 400 machine, equipped with a 400 W fibre laser and a build platform of 250 x 250 mm^2. Processing was carried out in an argon atmosphere with an oxygen control of < 0.1% and preheating the building platform at 150°C. The samples were built using an energy density in the range 35-45 J/mm^3, a layer thickness of 60 µm and a stripe scanning strategy in order to minimise the residual stresses generated during the process. The support

Element	Ni	Cr	Fe	Nb+Ta	Mo	Ti	Al	Co	Mn	Si	O	N	C	S
Wt.%	Balance	19.1	18.6	4.9	3.1	0.9	0.5	0.02	0.01	0.04	0.02	0.01	0.04	0.003

Table 6 Chemical composition of IN718 powder [3]

Control factor	Symbol	Unit	Level 1	Level 2
Sample mov.	A	-	without	with
Bubbling	B	-	without	1 aerator
US	C	-	without	with
Eductor	D	L/min	without	0.48
Time	E	min	30	60
Temperature	F	°C	35	40
Control factor	Symbol	Unit	Level 1	Level 2
Eductor	A	L/min	without	0.95
Bubbling	B	-	without	2 aerators
Temperature	C	°C	35	50

Table 7 DoE settings for roughness and mass evaluation on flat (top) and cantilever (bottom) samples [3]

Exp	Control factors					
	Sample movement (A)	Bubbling (B)	US (C)	Eductor (D)	Time (E)	Temperature (F)
1	-	-	-	-	-	-
2	-	-	-	+	+	+
3	-	+	+	-	+	+
4	-	+	+	+	-	-
5	+	-	+	-	-	+
6	+	-	+	+	+	-
7	+	+	-	-	+	-
8	+	+	-	+	-	+

Exp	Control factors		
	Eductor (A)	Bubbling (B)	Temperature (C)
1	-	-	-
2	-	+	+
3	+	-	+
4	+	+	-

Table 8 L_8 experimental matrix for 1st and L_4 experimental matrix for 2nd DoE [3]

structures used were designed both for boosting the heat dissipation and for subsequent chemical dissolution.

Two different part geometries were selected to investigate the roughness and support dissolution with the same electrolyte (etching agent); a flat plate geometry and a cantilever geometry. The flat plate geometry was selected to evaluate the importance of certain parameters on surface roughness and mass reduction and the cantilevers were used to validate the applicability of these initial results to the dissolution of support structures.

A Fractional Factorial based Taguchi methodology Design of Experiments (DoE) was used to optimise the main etching process parameters in order to obtain the highest surface roughness decrease and the highest mass reduction.

The parameter selection was based on previous experience and on information from a literature review. Etchant composition and concentration, temperature and process time are the main parameters affecting the etching process of IN718. In this study, the etchant was kept constant as a modified aeronautical approved etchant and temperature and time were selected as DoE factors. Parameters related to etchant movement and hydrodynamics were also selected as factors in the DoE, since gas formation during etching, heat evolution by exothermic etching reactions, or mechanical agitation induces large-scale convection in the etching solution and this form of material transport contributes to a fast and homogeneous etching. The selected parameters related to electrolyte movement have been ultrasonic stirring (US), air bubbling, etchant recirculation with an eductor and sample movement. The levels and settings for each of the parameters are detailed in Table 7 and Table 8.

The statistical measure of performance used to evaluate product quality was the so-called signal-to-noise (S/N) ratio. When analysing the signal-to-noise ratio, the larger the difference between the lower and upper limit, the more relevant the corresponding parameter will be in the process.

Surface roughness characterisation of as-built and treated samples was carried out using a profilometer. The average value of standard surface roughness Ra (arithmetical mean) was reported according to the ISO 25178 standard. Measurements were performed on three random areas on the y-axis per sample. Results were shown as the % roughness reduction, due to rough-

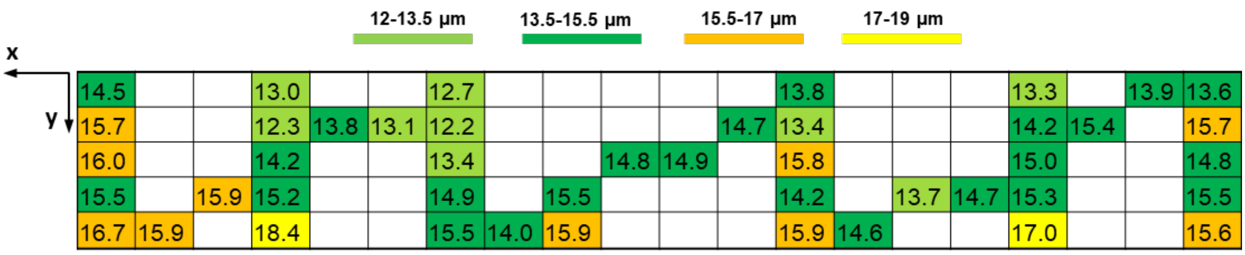

Fig. 7 Roughness (Ra in µm) of flat samples in the as-built condition according to their position on the build plate [3]

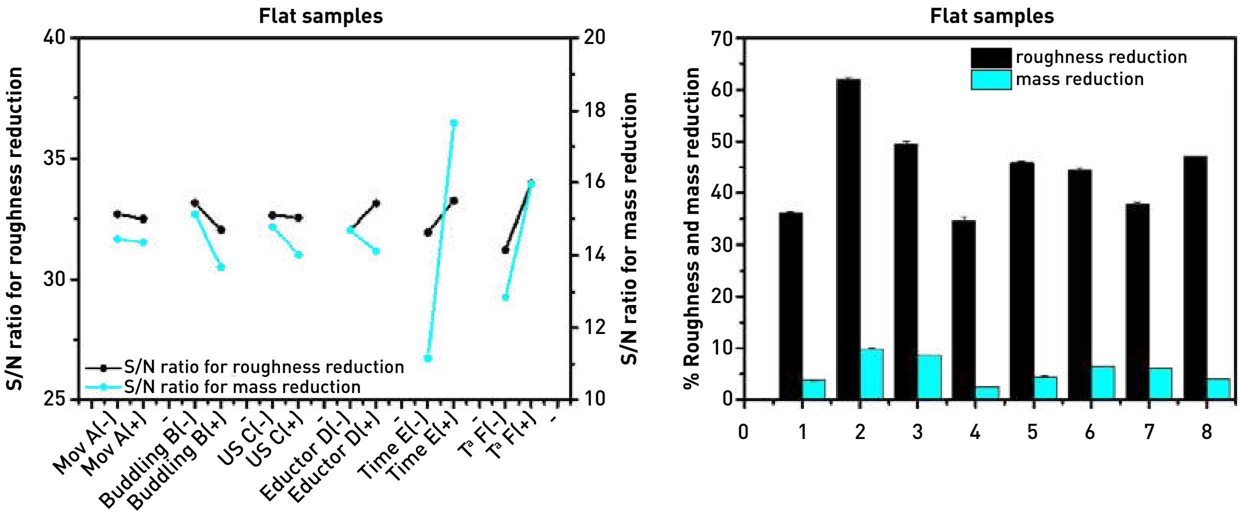

Fig. 8 Main effects plot both for S/N ratio of 1st DoE (right) and roughness and mass reduction (left) [3]

ness differences in the as-built parts produced by PBF-LB (see Fig. 8). Mass reduction was evaluated using a precision balance, measuring the mass before and after the chemical treatment.

The results of the first DoE are shown in Table 9 and plotted in Fig. 8. It can be observed that both surface roughness and mass reduction are mainly affected by temperature and time, in accordance with previously published results. With reference to the parameters related to electrolyte movement, bubbling and electrolyte movement with an eductor seem to be the parameters with most effect on surface roughness reduction.

In order to evaluate the effect of chemical etching on support removal, the second DoE, detailed in Table 7 and Table 8, was carried out to consider parameters and levels that led to a higher mass reduction

Control factor	Symbol	Level 1	Level 2	Difference	Rank
Sample mov.	A	32.69	32.51	0.19	5
Bubbling	B	33.16	32.04	1.12	3
US	C	32.64	32.55	0.09	6
Eductor	D	32.04	33.15	1.11	4
Time	E	31.94	33.26	1.32	2
Temperature	F	31.22	33.98	2.75	1
Control factor	**Symbol**	**Level 1**	**Level 2**	**Difference**	**Rank**
Sample mov.	A	14.45	14.35	0.09	6
Bubbling	B	15.13	13.67	1.46	3
US	C	14.79	14.01	0.78	4
Eductor	D	14.69	14.11	0.58	5
Time	E	11.15	17.65	6.50	1
Temperature	F	12.84	15.96	3.12	2

Table 9 S/N response of roughness (top) and mass (bottom) reduction for 1st DoE [3]

Control factor	Symbol	Level 1	Level 2	Difference	Rank
Eductor	A	34.90	35.88	0.98	2
Bubbling	B	35.19	35.58	0.39	3
Temperature	C	34.22	36.55	2.33	1
Control factor	**Symbol**	**Level 1**	**Level 2**	**Difference**	**Rank**
Eductor	A	33.40	32.05	1.35	2
Bubbling	B	33.38	32.07	1.32	3
Temperature	C	34.30	31.15	3.15	1

Table 10 S/N response of roughness (top) and mass (bottom) reduction for 2nd DoE [3]

but expanding their level. Time was fixed at its upper level, considering temperature as a variable parameter and increasing its value. Bubbling and electrolyte movement with an eductor were also selected as parameters but with higher values to evaluate whether these movements allow the etchant to penetrate further between the supports and, thus, achieve a faster dissolution.

Table 10 and Fig. 9 show the results obtained in this second DoE. Again, and as previously reported in the literature for other materials treated by chemical etching, temperature is the factor that most influences surface roughness and mass reduction and, the higher the temperature, the higher the surface roughness and mass reduction. However, factors such as sample movement or bubbling do not seem to follow this same relationship. Further research needs to be carried out to analyse this behaviour, since very little literature has been published on the subject.

The next step in the Taguchi methodology comprised solving a prediction equation, in which a projection of the % roughness and mass decrease is obtained according to the optimum parameters sequence. In this case, the optimal combination of factors for highest surface roughness reduction was A1-B1-C1-D2-E2-F2 and, for highest mass reduction, A1-B1-C1-D1-E2-F2. On the other hand, the combinations A2-B2-C1 and A1-B1-C1 achieved both the major surface roughness and mass reductions when working with cantilevers.

A good agreement was found between the experimental and the predicted results, confirming that the experimentation based on the Taguchi method had been properly conducted to explore the system response for the different levels of the input parameters (control factors).

Feasibility of grain refinement by heterogeneous nucleation in molybdenum PBF-LB

The final paper turned attention to the AM processing of refractory metals. This paper was by L Kaserer, L Rissbacher, J Braun, G Leichtfried (University of Innsbruck, Austria) and H Kestler (Plansee SE, Austria) and addressed the feasibility of grain refinement by heterogeneous nucleation in molybdenum processed by PBF-LB [4].

PBF-LB Mo components show a coarse, epitaxially grown columnar microstructure interspersed with cracks. These defects can be effec-

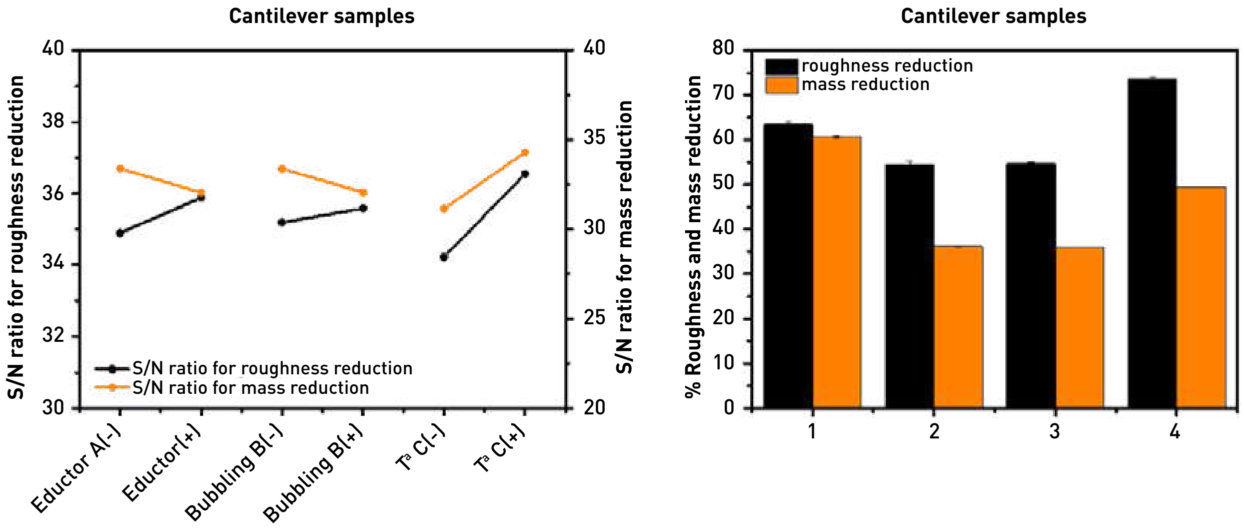

Fig. 9 Main effects plot both for S/N ratio of 2nd DoE (right) and roughness and mass reduction (left) [3]

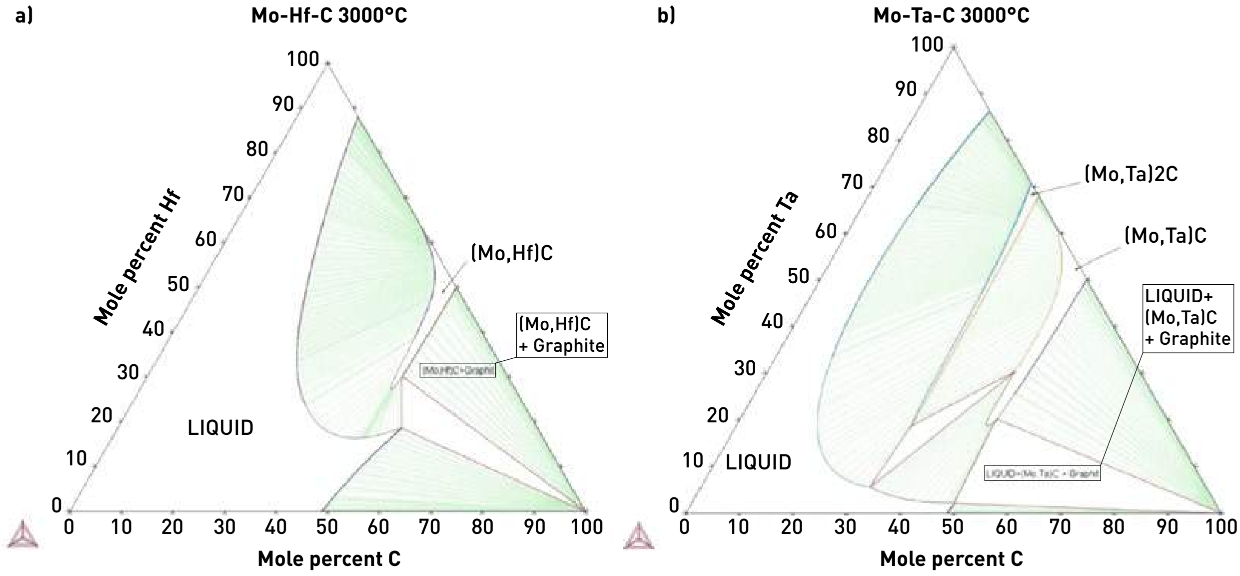

Fig. 10 Ternary phase diagrams for a) Hf–Mo–C and b) Ta–Mo–C at 3,000°C [4]

tively suppressed by alloying with carbon. An addition of 3.5 at.% carbon triggers cellular solidification and grain refinement to a size of approx. 36 µm, through the effect of constitutional supercooling. The grains of carbon-modified Mo are composed of colonies of α-Mo cells with a crystallographic misorientation angle of < 0.5°. The individual cells have a size of approximately 1 µm and are surrounded by a Mo_2C network. The mean grain size compared to pure Mo is significantly reduced; with increasing content of carbon up to the eutectic composition, the constitutional supercooling and hence the grain refinement increases. With a content of 15 at.% C, which is just below the eutectic composition of 17 at.%, a grain size of approx. 10 µm is achieved [5]. However, as the carbon content increases, the volume fraction of Mo_2C also increases. For Mo with 3.5 at.% carbon, the Mo_2C content is 8.5 vol.%.

This results in an increase in strength and hardness, but also in embrittlement. In order to achieve strong grain refinement without simultaneous embrittlement, an alternative grain refining mechanism would have to be used. In other alloy systems, such as aluminium alloys, the addition of heterogeneous grain refiners is carried out with great success. While grain refinement by heterogeneous nucleation is the preferred approach for grain refinement in many alloying systems in PBF-LB, its feasibility for Mo-based alloys has not yet been demonstrated.

The work reported was aimed at evaluating, both theoretically and experimentally, the feasibility of grain refinement through introducing particles that act as potent nucleate particles seeding equiaxed grains in Mo processed by PBF-LB.

Suitable compounds that can act as potent nucleate particles need to have the smallest possible lattice mismatch with the α-Mo matrix and either need to remain stable and solid or form in-situ in the Mo melt. Identifying suitable compounds for Mo is challenging due to its high melting point (2,623°C). The compounds with the highest reported melting points are the carbides hafnium carbide, (HfC) and tantalum carbide (TaC), at 4,000°C and 3,770°C, respectively. They have a body-centred cubic structure and a lattice mismatch δ of 0.47 (HfC) and 0.42 (TaC) compared to Mo. They are, in principle, suitable nucleating agents. However, simulations show that the temperatures in a PBF-LB Mo melt pool can locally exceed the melting points of both carbides and reach Mo's boiling point of 4,639°C.

In the thermodynamic equilibrium, both carbides will not remain stable in the Mo melt, but dissociate. Also, according to the ternary phase diagrams, the in-situ formation of Hf/Ta carbides in the Mo melt does not occur at concentrations of these

"While grain refinement by heterogeneous nucleation is the preferred approach for grain refinement in many alloying systems in PBF-LB, its feasibility for Mo-based alloys has not yet been demonstrated."

Sample	Sieve size	Powder density	Chemical analysis
Mo-TaC	63 µm	Bulk: 5.1 ± 0.1 g/cm^3 Tap: 5.9 ± 0.1 g/cm^3	Ta: 1.96 at.% C: 1.89 at.% Impurity content: O: 0.160 at.% N: < 0.001 at.% H: < 0.001 at.%
Mo-HfC	63 µm	Bulk: 5.3 ± 0.1 g/cm^3 Tap: 5.6 ± 0.1 g/cm^3	Hf: 6.40 at.% C: 6.56 at.% Impurity content: O: 0.536 at.% N: < 0.001 at.% H: < 0.001 at.%

Table 11 Powder properties [4]

alloying elements that allow a material with high metallic phase fraction. The isothermal sections of the respective ternary phase diagrams at 3,000°C shown in Fig. 10 (a) and (b) illustrate this fact.

Deviations from these theoretical predictions may occur and HfC and TaC may partially remain stable in the melt if the dissociation temperature of the carbides is only exceeded locally in the Mo melt and/or the high heating and cooling rates in PBF-LB prevent the thermodynamic equilibrium state from being reached.

In the experimental programme, spherical Mo powder with metallic purity of > 99.9% was mixed with TaC and HfC nanopowders using a ball mill. The milling parameters were chosen so that the nanopowders were homogeneously distributed on the surface of the spherical Mo particles. Subsequently, the powders were sieved at a mesh size of 63 µm. Preliminary tests showed that the Mo-HfC samples had a significantly lower Hf and C content after PBF-LB production, than would correspond to the added amount of HfC. For Mo-TaC samples, this was not observed. This might be due to poorer adhesion of the HfC nanopowder particles to the Mo powder particles than is the case with TaC. Therefore, significantly more HfC (12 wt.%) than TaC (4 wt.%) nanopowder was added to Mo to compensate for the expected loss.

Table 11 summarises the properties of the powder mixtures. The tap/bulk density was measured according to ASTM B527, the chemical specifications for C were measured using the combustion method (LECO CS-230), for O, N, H carrier gas hot extraction (LECO TC-500), and, for Ta and Hf, using XRF spectroscopy.

The PBF-LB processing was performed on an AconityLAB system. Samples with a size of 10 x 10 x 10 mm were produced.

Table 12 shows the properties of the Mo-TaC and Mo-HfC PBF-LB samples. Both samples showed equally high densities, indicating good processability of both powders. The carbon content of Mo-HfC is higher than that of Mo-TaC, because the amount of carbide added to the starting powder was higher. Mo-HfC samples also show a smaller mean grain size and a higher hardness compared to Mo-TaC.

The mean grain sizes in Table 12 were calculated from the area in the corresponding EBSD images. These images showed a higher degree of grain refinement and the stronger suppression of columnar grains in the side view in Mo-HfC compared to TaC. For both samples, the EBSD maps did not show evidence of the formation of equiaxed grains. This statement is also true for the EBSD maps at higher magnification.

Sample	Density	Chemical analysis	Mean grain size (area fraction)	Hardness
Mo-TaC	10.11 ± 0.01 g/cm^3	Ta: 1.96 at.% C: 1.82 at.% Impurity content: O: 0.013 at.% N: < 0.001 at.% H: < 0.001 at.%	Side view: 56 ± 39 µm Top view: 30 ± 17 µm	316 ± 12 HV10
Mo-HfC	10.11 ± 0.01 g/cm^3	Hf: 3.66 at.% C: 2.90 at.% Impurity content: O: 0.540 at.% N: < 0.001 at.% H: < 0.001 at.%	Side view: 24 ± 18 µm Top view: 18 ± 14 µm	435 ± 11 HV10

Table 12 Comparison of physical, chemical, crystallographic, and mechanical properties of the PBF-LB samples [4]

The microstructure investigated by SEM and EDX is shown in Fig. 11, representative of both samples for Mo-HfC. It shows a cellular sub-grain structure consisting of cells surrounded by a carbide network. The cell size was related to the position in the melt pool and was smaller for areas close to the melt pool boundary on the inner side of the former melt pool. EDX measurements revealed that cells, in the case of Mo-HfC, contained Mo and Hf and, in the case of Mo-TaC, Mo and Ta. Hf or Ta was at least partially dissolved in Mo.

Consequently, the hardness of Mo-HfC and Mo-TaC was increased compared to samples with the same amount of carbon (see Fig. 12 (a)). Hf and Ta lead to solid solution hardening and thus to further embrittlement of the material. The phase surrounding the cells as a network contained Hf/Ta, Mo, and C. It can be assumed that Hf/Ta form ternary carbides with Mo. The microstructure was similar to that of Mo alloyed only with carbon, except that Hf and Ta were dissolved in Mo, forming ternary carbides instead of Mo carbide.

It can be concluded that TaC and HfC completely dissociate in the Mo melt during the PBF-LB process and, thus, have no effect as heterogeneous grain refiners.

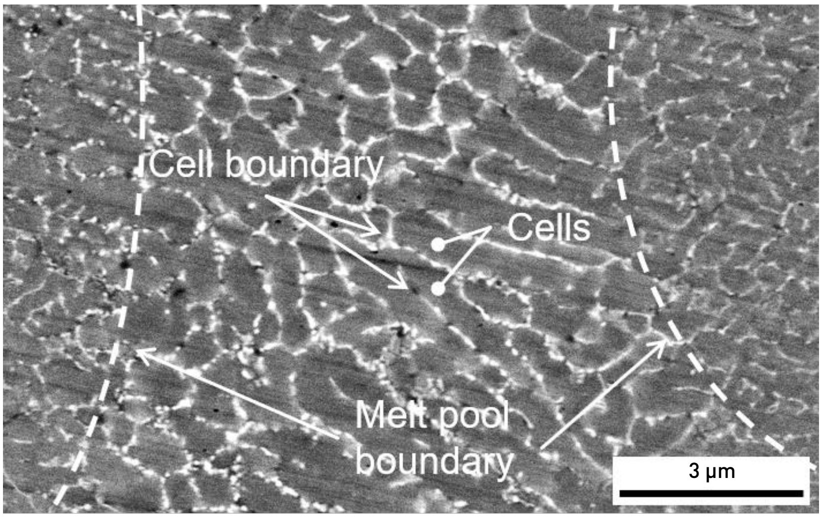

Fig. 11 SEM image showing the cellular sub-grain structure of the Mo-HfC sample. The cell size is related to the position in the melt pool. EDX measurements show that cells contain Mo and Hf, while the cell boundary contains Mo, Hf, and C. For Mo-TaC, similar results are obtained, except that Hf is exchanged with Ta [4]

The effects of HfC and TaC additions on the mean grain size, compared to additions of the same amount of C, are shown quantitatively in Fig. 12 (b), Ta and Hf have a mild grain refining effect, which enhances the effect of C. However, the main mechanism for grain refinement in Mo-TaC/HfC is still triggered by carbon-induced constitutional supercooling. Calculating the growth restriction factor Q supports this statement. Carbon has a Q value of 23 K/at.% in Mo. Hf and Ta contribute slightly through different mechanisms. The effect of Hf can also be attributed to constitutional supercooling. Calculating Q for Hf in Mo gives a value of 4 K/at.%. C is approximately six times more effective as a grain refining agent in Mo than Hf. For Ta, constitutional supercooling cannot cause grain refinement, since Ta has full solubility in Mo. The grain-refining effect of Ta in Mo might be explained by the fact that it hinders the diffusion

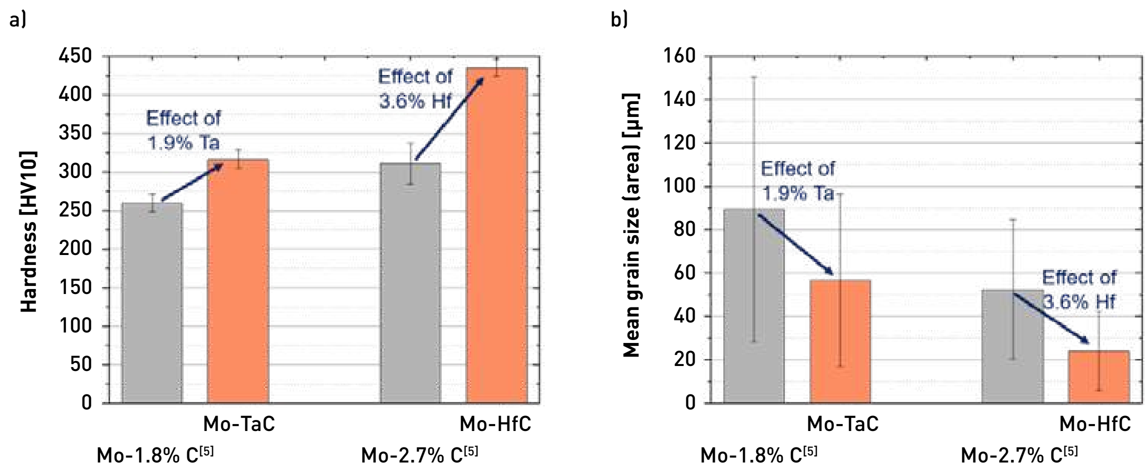

Fig. 12 a) Mean grain size (side view) and b) hardness of Mo-TaC and Mo-HfC samples compared to samples with similar carbon contents to show the effect of Ta and Hf. Percentages in at.% [4]

of carbon in the Mo melt. Thus, Ta might cause the carbon concentration in front of the solid-liquid interface to have a steeper gradient and slightly increase the constitutional supercooling effect of C.

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[4] Lukas Kaserer, University of Innsbruck, Austria.
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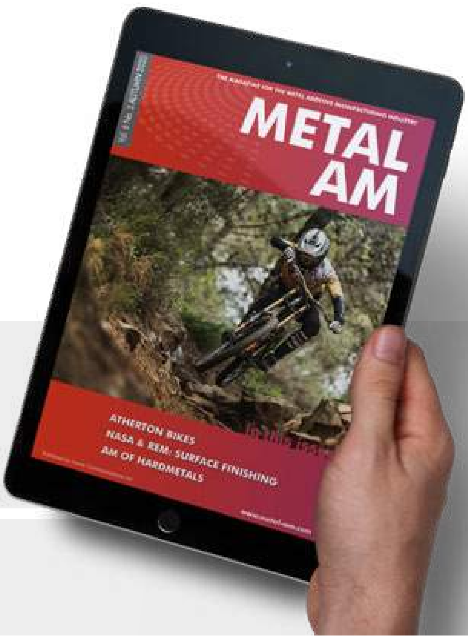

Advertisers' index & buyer's guide

Our advertisers' index serves as a convenient guide to suppliers of AM machines, materials, part manufacturing services, software and associated production equipment. In the digital edition of *Metal AM* magazine, available at www.metal-am.com, or via the *Metal Additive Manufacturing* app, simply click on a company name to view its advert, or on the weblink to go directly to its website.

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CM Furnaces Inc. 54
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CREMER Thermoprozessanlagen GmbH 66
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Elnik Systems 18
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www.loemi.com

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T-M Vacuum Products Inc 118
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TAV Vacuum Furnaces SPA 103
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Toll debinding & sintering

DSH Technologies 110
www.dshtech.com

Gas & gas analysis

Cambridge Sensotec Limited 42
www.cambridge-sensotec.co.uk

NEL Hydrogen 87
www.nelhydrogen.com

Process Sensing Technologies 61
www.processsensing.com

Alphabetical index

more >>>

HIP SYSTEMS & SERVICES

more >>>

PRE & POST-PROCESSING TECHNOLOGY

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Metal powder

Powder processing, classification & analysis

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MATERIALS

Metal powder atomisers

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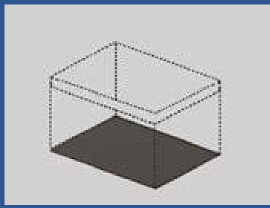

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